

**Emission Factor Documentation for AP-42  
Section 11.7**

**CERAMIC PRODUCTS MANUFACTURING**

**Final Report**

**For U. S. Environmental Protection Agency  
Office of Air Quality Planning and Standards  
Emission Factor and Inventory Group**

**EPA Contract 68-D2-0159  
Work Assignment No. III-01**

**MRI Project No. 4603-01**

**June 1996**

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For U. S. Environmental Protection Agency  
Office of Air Quality Planning and Standards  
Emission Factor and Inventory Group  
Research Triangle Park, NC 27711

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## NOTICE

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## PREFACE

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EMISSION FACTOR DOCUMENTATION FOR AP-42 SECTION 11.7  
Ceramic Products Manufacturing

1. INTRODUCTION

The document *Compilation of Air Pollutant Emission Factors* (AP-42) has been published by the U. S. Environmental Protection Agency (EPA) since 1972. Supplements to AP-42 have been routinely published to add new emission source categories and to update existing emission factors. AP-42 is routinely updated by EPA to respond to new emission factor needs of EPA, State and local air pollution control programs, and industry.

An emission factor is a representative value that attempts to relate the quantity of a pollutant released to the atmosphere with an activity associated with the release of that pollutant. Emission factors usually are expressed as the weight of pollutant divided by the unit weight, volume, distance, or duration of the activity that emits the pollutant. The emission factors presented in AP-42 may be appropriate to use in a number of situations, such as making source-specific emission estimates for areawide inventories for dispersion modeling, developing control strategies, screening sources for compliance purposes, establishing operating permit fees, and making permit applicability determinations. The purpose of this report is to provide background information from test reports and other information to support revisions to AP-42 Section 8.7, Ceramic Clay Manufacturing.

This background report consists of five sections. Section 1 includes the introduction to the report. Section 2 gives a description of the ceramic clay manufacturing industry. It includes a characterization of the industry, a description of the different process operations, a characterization of emission sources and pollutants emitted, and a description of the technology used to control emissions resulting from these sources. Section 3 is a review of emission data collection (and emission measurement) procedures. It describes the literature search, the screening of emission data reports, and the quality rating system for both emission data and emission factors. Section 4 details how the revised AP-42 section was developed. It includes the review of specific data sets, a description of how candidate emission factors were developed, and a summary of changes to the AP-42 section. Section 5 presents the AP-42 Section 11.7, Ceramic Products Manufacturing.

## 2. INDUSTRY DESCRIPTION

### 2.1 INDUSTRY CHARACTERIZATION<sup>1-3</sup>

Ceramics are defined as a class of inorganic, nonmetallic solids that are subject to high temperature in manufacture and/or use. The most common ceramics are composed of oxides, carbides, and nitrides. Silicides, borides, phosphides, tellurides, and selenides also comprise ceramics. Ceramic processing generally involves high temperatures, and the resulting materials are heat resistant or refractory.

Ceramic manufacturing is classified under several Standard Industrial Classification (SIC) codes. These SIC codes are listed in Table 2-1.

TABLE 2-1. STANDARD INDUSTRIAL CLASSIFICATION CODES FOR CERAMIC PRODUCTS MANUFACTURING

SIC	Title
3253	Ceramic wall and floor tile
3261	Vitreous plumbing fixtures
3262	Vitreous china table and kitchenware
3263	Semivitreous table and kitchenware
3264	Porcelain electrical supplies
3269	Pottery products, not elsewhere classified

In addition, ceramic fiber is classified under SIC 3299, nonmetallic mineral products, not elsewhere classified.

In 1987, more than 1,100 ceramic manufacturing facilities classified under these SIC codes were operating in the United States. The majority of these facilities were relatively small operations engaged in the manufacture of pottery products. However, there were more than 300 ceramic manufacturing facilities with at least 20 employees. Table 2-2 lists the total number of ceramics manufacturers by State and SIC code, and Table 2-3 lists the number of manufacturers with at least 20 employees in 1987. In terms of number of facilities, the leading ceramic manufacturing States in 1987 were California, Ohio, Texas, Pennsylvania, New York, and New Jersey.

Traditional ceramics refers to ceramic products that are produced from unrefined clay and combinations of refined clay and powdered or granulated nonplastic minerals. Often, traditional ceramics is used to refer to ceramics in which the clay content exceeds 20 percent. The general classifications of traditional ceramics are described below.

Pottery is sometimes used as a generic term for ceramics that contain clay and are not used for structural, technical, or refractory purposes.

TABLE 2-2. LOCATION OF CERAMIC MANUFACTURERS IN 1987<sup>a</sup>

State	SIC Code						Total
	3253	3261	3262	3263	3264	3269	
Alabama	3	2				6	11
Arizona					1		1
California	20	12	4	12	21	149	218
Colorado					4	11	15
Connecticut		1					1
Florida	6					37	43
Georgia	4	4			2		10
Illinois		4			5	13	22
Indiana		3					3
Kentucky	3	1				14	18
Maryland					2		2
Michigan					4	18	22
Mississippi	2	1					3
New Jersey	4	5	1		13	21	44
New York	5		5		13	32	55
North Carolina	2		2			22	26
Ohio	13	6	5	5	9	38	76
Oklahoma	1				1	5	7
Oregon						27	27
Pennsylvania	3	3	2	4	12	35	59
South Carolina		1			2		3
Tennessee	4				4	15	23
Texas	15	8				38	61
West Virginia			1		3		4
Wisconsin		1			1	15	17
Other States	29	13	14	23	19	258	356
Total	114	65	34	44	116	754	1,127
Value of shipments, \$ million	717.4	790.6	298.4	93.0	714.2	519.7	2,243

<sup>a</sup>Reference 2.

TABLE 2-3. LOCATION OF CERAMIC MANUFACTURERS IN 1987  
WITH 20 OR MORE EMPLOYEES<sup>a</sup>

State	SIC Code						Total
	3253	3261	3262	3263	3264	3269	
Alabama	2	1				1	4
Arizona					1		1
California	8	6	1	6	8	31	60
Colorado					1	2	3
Connecticut		1					1
Florida	3					2	5
Georgia	2	2			1		5
Illinois		2			2	5	9
Indiana		3					3
Kentucky	3	1				6	10
Maryland					1		1
Michigan					2	2	4
Mississippi	2	1					3
New Jersey	1	4	1		10	7	23
New York	1		2		9	3	15
North Carolina	2		1			2	5
Ohio	8	5	4	3	7	14	41
Oklahoma	1				1	2	4
Oregon						1	1
Pennsylvania	3	2	2	3	8	6	24
South Carolina		1			2		3
Tennessee	2				4	3	9
Texas	8	6				4	18
West Virginia			1		2		3
Wisconsin		1			1	4	6
Other States	5	4	2	6	6	20	43
Total	51	40	14	18	66	115	304

<sup>a</sup>Reference 2.

Whiteware refers to ceramic ware that is white, ivory, or light gray in color after firing. Whiteware is further classified as earthenware, stoneware, chinaware, porcelain, and technical ceramics.

Earthenware is defined as glazed or unglazed nonvitreous (porous) clay-based ceramic ware. Applications for earthenware include artware, kitchenware, ovenware, tableware, and tile.

Stoneware is vitreous or semivitreous ceramic ware of fine texture, made primarily from nonrefractory fire clay or some combination of clays, fluxes, and silica that, when fired, has properties similar to stoneware made from fire clay. Applications for stoneware include artware, chemicalware, cookware, drainpipe, kitchenware, tableware, and tile.

Chinaware is vitreous ceramic ware of zero or low absorption after firing that is used for nontechnical applications. Applications for chinaware include artware, ovenware, sanitaryware, and tableware.

Porcelain is defined as glazed or unglazed vitreous ceramic ware used primarily for technical purposes. Applications for porcelain include artware, ballmill balls, ballmill liners, chemicalware, insulators, and tableware.

Technical ceramics include vitreous ceramic whiteware used for such products as electrical insulation, or for chemical, mechanical, structural, or thermal applications.

Ceramic products that are made from highly refined natural or synthetic compositions and designed to have special properties are referred to as advanced ceramics. Advance ceramics can be classified according to application as electrical, magnetic, optical, chemical, thermal, mechanical, biological, and nuclear.

Most ceramic products are clay-based and are made from a single clay or one or more clays mixed with mineral modifiers such as quartz and feldspar. The types of commercial clays used for ceramics are primarily kaolin and ball clay.

## 2.2 PROCESS DESCRIPTION<sup>1,3-5</sup>

Figure 2-1 presents a general process flow diagram for ceramic products manufacturing. The basic steps include raw material procurement, beneficiation, mixing, forming, green machining, drying, presinter thermal processing, glazing, firing, final processing, and packaging. The following paragraphs describe these operations in detail. Figure 2-2 shows miscellaneous ceramic products manufacturing processes and equipment.

### 2.2.1 Raw Material Procurement

To begin the process, raw materials are transported and stored at the manufacturing facility. The raw materials used in the manufacture of ceramics range from relatively impure clay materials mined from natural deposits to ultrahigh purity powders prepared by chemical synthesis. Naturally occurring raw materials used to manufacture ceramics include silica, sand, quartz, flint, silicates, and aluminosilicates (e.g., clays and feldspar).

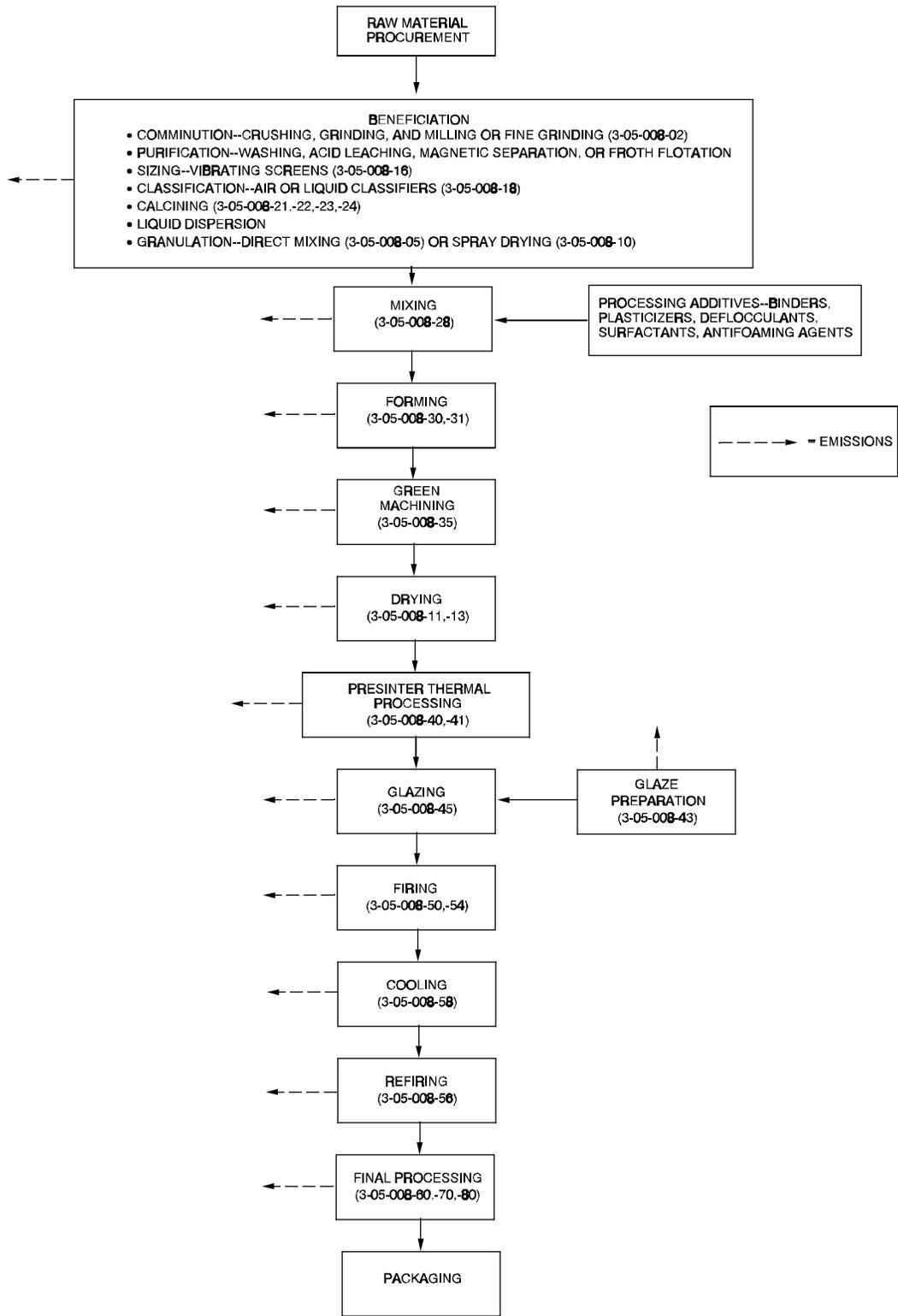
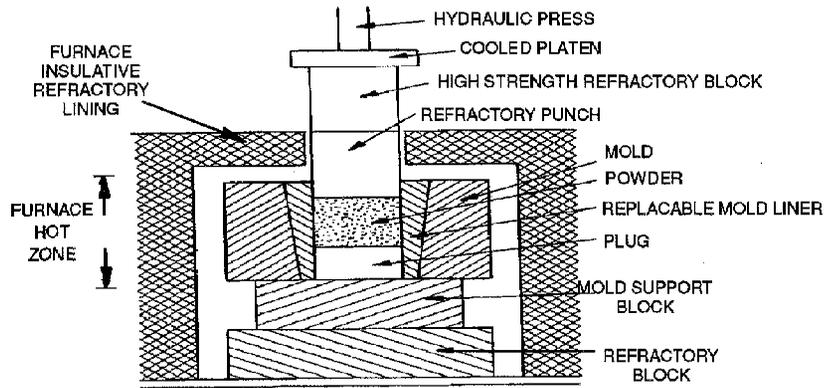
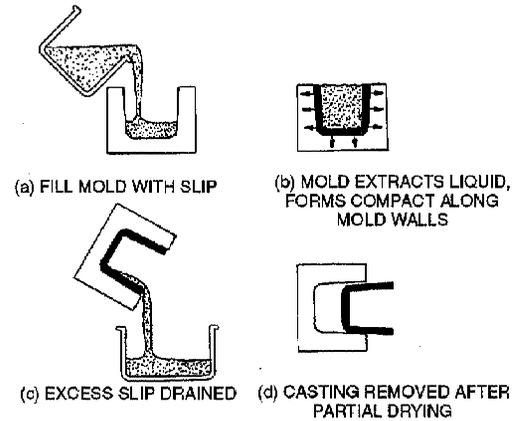


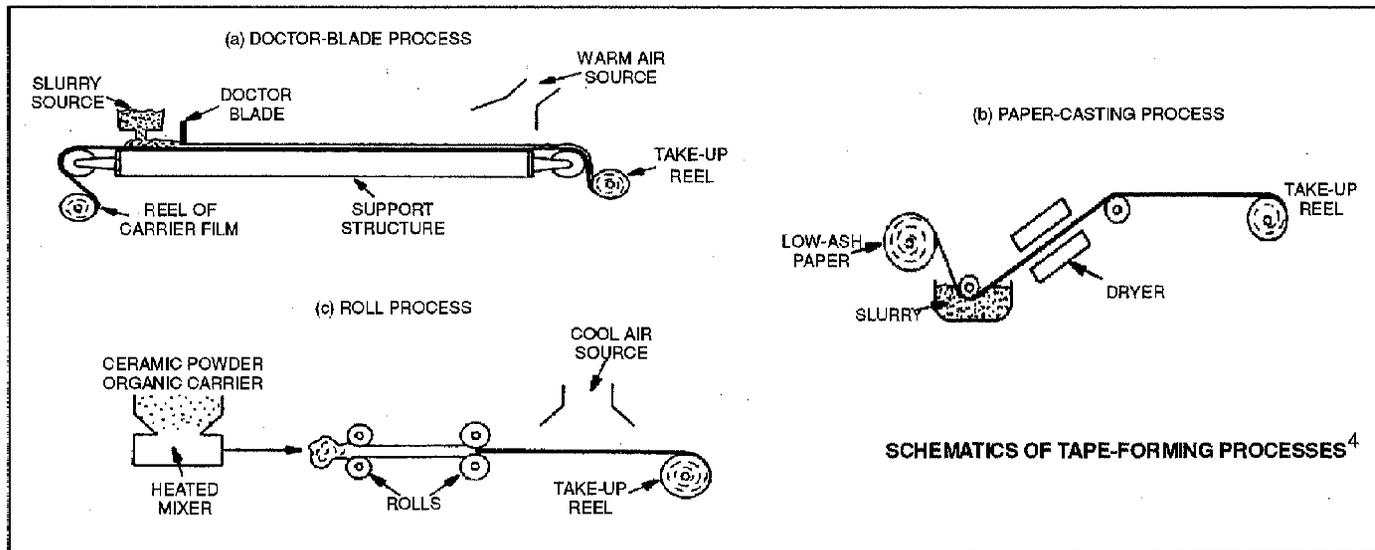
Figure 2-1. Process flow diagram for ceramic products manufacturing.



**SCHEMATIC SHOWING THE ESSENTIAL ELEMENTS OF A HOT PRESS<sup>4</sup>**

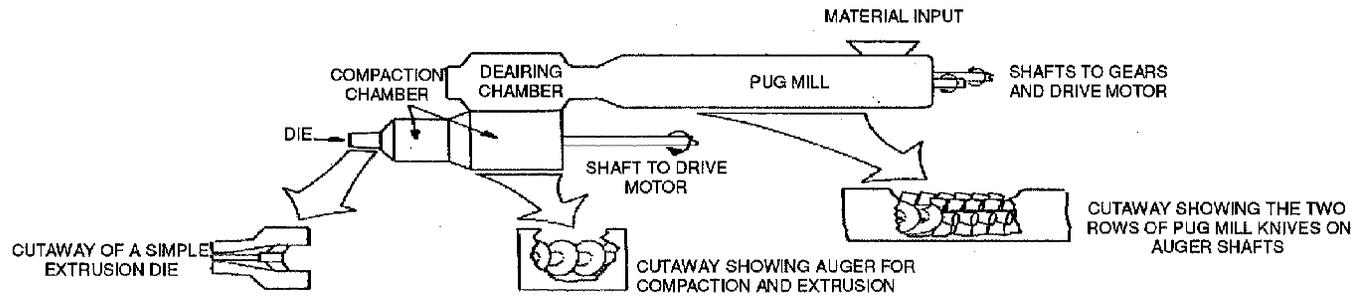


**SCHEMATIC ILLUSTRATING THE DRAIN-CASTING PROCESS<sup>4</sup>**

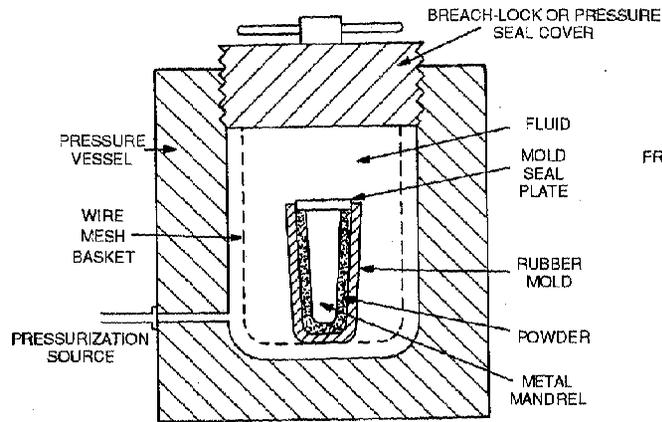


**SCHEMATICS OF TAPE-FORMING PROCESSES<sup>4</sup>**

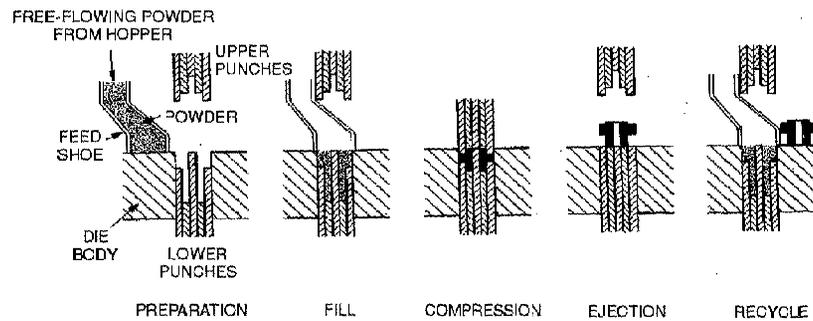
Figure 2-2. Miscellaneous ceramic products manufacturing processes and equipment.<sup>4,5</sup>



**SCHEMATIC OF AN EXTRUDER<sup>4</sup>**

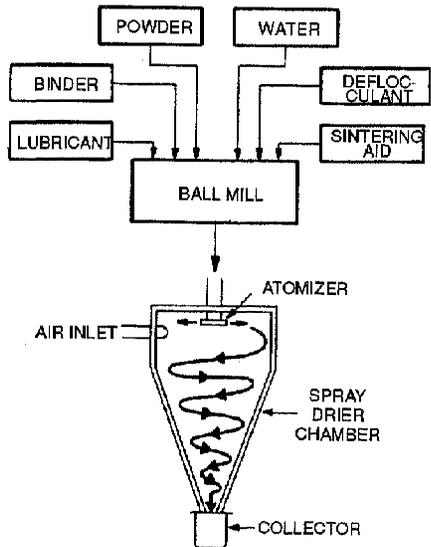


**SCHEMATIC OF AN ISOSTATIC PRESSING SYSTEM<sup>4</sup>**

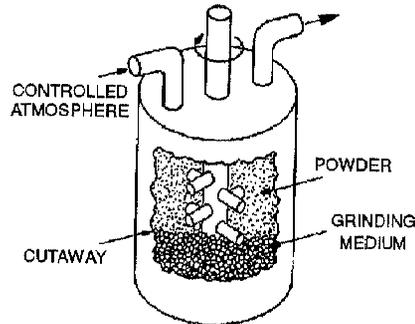


**TYPICAL SINGLE-STROKE AUTOMATED MECHANICAL PRESS CYCLE<sup>5</sup>**

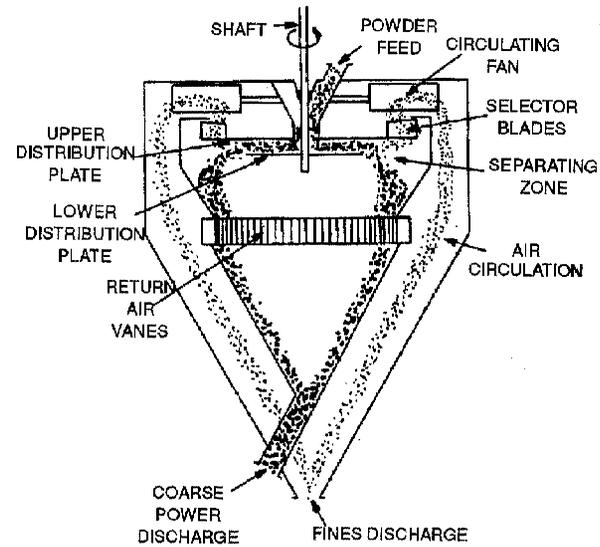
Figure 2-2. (continued)



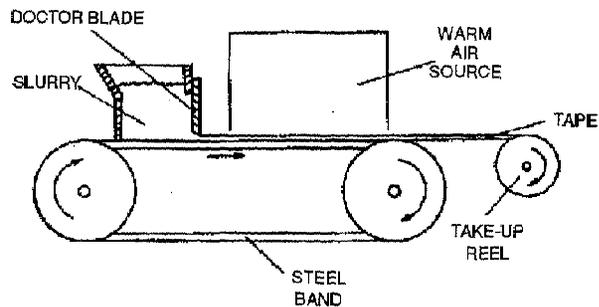
**SCHEMATIC OF THE SPRAY-DRYING PROCESS FOR ACHIEVING FREE-FLOWING SPHERICAL POWDER AGGLOMERATES CONTAINING A UNIFORM LEVEL OF ADDITIVES** <sup>4</sup>



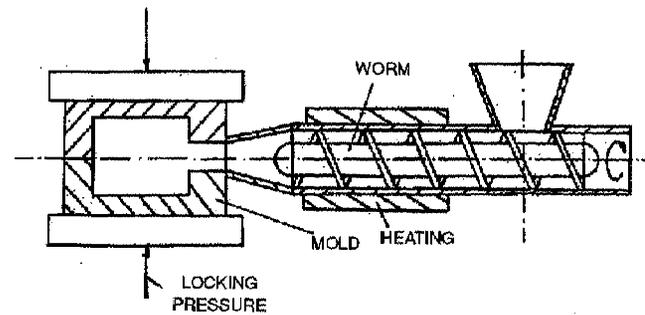
**SCHEMATIC OF AN ATTRITION MILL** <sup>4</sup>



**DRAWING OF AN AIR CLASSIFIER, SHOWING THE PATHS OF THE COARSE AND FINE PARTICLES** <sup>4</sup>



**PRINCIPLE OF THE TAPE CASTING PROCESS** <sup>5</sup>



**PRINCIPLE OF THE INJECTION MouldING PROCESS** <sup>5</sup>

Figure 2-2. (continued)

### 2.2.2 Beneficiation

The next step in the process is beneficiation. Although chemically synthesized ceramic powders also require some beneficiation, the focus of this discussion is on the processes for beneficiating naturally occurring raw materials. The basic beneficiation processes include comminution, purification, sizing, classification, calcination, liquid dispersion, and granulation. Naturally occurring raw materials often undergo some beneficiation at the mining site or at an intermediate processing facility prior to being transported to the ceramic manufacturing facility.

Comminution entails reducing the particle size of the raw material by crushing, grinding, and milling or fine grinding. The purpose of comminution is to liberate impurities, break up aggregates, modify particle morphology and size distribution, facilitate mixing and forming, and produce a more reactive material for sintering. Primary crushing generally reduces material up to 0.3 meter (m) (1 foot [ft]) in diameter down to 1 centimeter (cm) (0.40 inch [in.]) in diameter. Secondary crushing reduces particle size down to approximately 1 millimeter (mm) (0.04 in.) in diameter. Fine grinding or milling reduces the particle size down to as low as 1.0 micrometer ( $\mu\text{m}$ ) ( $4 \times 10^{-5}$  in.) in diameter. Ball mills are the most commonly used piece of equipment for milling. However, vibratory mills, attrition mills, and fluid energy mills also are used. Ball mills consist of closed containers that are filled with grinding media and rotated to induce a cascading action of the media. Attrition mills are fixed, closed containers filled with grinding media that is agitated by rotating arms. Vibratory mills consist of fixed containers lined with a flexible material and filled with grinding media that is vibrated. Fluid energy mills use a high velocity fluid such as air, water, or superheated steam to cause the material particles to impact one another. Crushing and grinding typically are dry processes; milling may be wet or dry processes. In wet milling, water or alcohol are commonly used as the milling liquid.

Several procedures are used to purify the ceramic material. Water soluble impurities can be removed by washing with deionized or distilled water and filtering, and organic solvents may be used for removing water-insoluble impurities. Acid leaching is sometimes employed to remove metal contaminants. Magnetic separation is used to extract magnetic impurities from either dry powders or wet slurries. Froth flotation also is used to separate undesirable materials.

Sizing and classification separate the material into size ranges. Sizing is most often accomplished using fixed or vibrating screens. Dry screening can be used to sizes down to  $44 \mu\text{m}$  (0.0017 in., 325 mesh). Dry forced-air sieving and sonic sizing can be used to size dry powders down to  $37 \mu\text{m}$  (0.0015 in., 400 mesh), and wet sieving can be used for particles down to  $25 \mu\text{m}$  (0.00098 in., 500 mesh). Classification processes use differences in how particles settle in a liquid (elutriation) or moving gas stream to separate coarse and fine fractions of ceramic powders. Air classifiers generally are effective in the range of  $420 \mu\text{m}$  to  $37 \mu\text{m}$  (0.0165 to 0.0015 in., 40 to 400 mesh). However, special air classifiers are available for isolating particles down to  $10 \mu\text{m}$  (0.00039 in.).

Calcining consists of heating a ceramic material to a temperature well below its melting point to liberate undesirable gases or other material and to bring about structural transformation to produce the desired composition and phase product. Calcining typically is carried out in rotary calciners, heated fluidized beds, or by heating a static bed of ceramic powder in a refractory crucible.

Liquid dispersion of ceramic powders sometimes is used to make slurries. Slurry processing facilitates mixing and minimizes particle agglomeration. The primary disadvantage of slurry processing is that the liquid must be removed prior to firing the ceramic.

Dry powders often are granulated to improve flow, handling, packing, and compaction. Granulation is accomplished by direct mixing, which consists of introducing a binder solution during powder mixing, or by spray drying. In spray drying, the ceramic powder in the form of a slurry is atomized by means of a pressure nozzle or rotary atomizer and sprayed toward the top of the drying chamber. A descending stream of heated air flowing countercurrent to the spray dries the slurry as dense, homogeneous, spherical granules, which are collected at the base of the dryer. Spray dryers generally are gas-fired and operate at temperatures of 110° to 130°C (230° to 270°F).

### 2.2.3 Mixing

The purpose of mixing or blunging is to combine the constituents of a ceramic powder to produce a more chemically and physically homogenous material for forming. Pug mills often are used for mixing ceramic materials. Several processing aids may be added to the ceramic mix during the mixing stage. Binders and plasticizers are used in dry powder and plastic forming; in slurry processing, deflocculants, surfactants, and antifoaming agents are added to improve processing. Liquids also are added in plastic and slurry processing.

Binders are polymers or colloids that are used to impart strength to green or unfired ceramic bodies. For dry forming and extrusion, binders amount to 3 percent by weight of the ceramic mixture. Some examples of binders are polyvinyl alcohol and polyethylene glycol.

Plasticizers and lubricants are used with some types of binders. Plasticizers increase the flexibility of the ceramic mix. Examples include adsorbed water, ethylene glycol, stearic acid, oleic acid, and glycerine. Lubricants, such as stearic acid and oleic acid, lower frictional forces between particles and reduce wear on equipment.

Water is the most commonly used liquid in plastic and slurry processing. Organic liquids such as alcohols may also be used in some cases. Deflocculants also are used in slurry processing to improve dispersion and dispersion stability. Some examples of deflocculants are monovalent cations for clay-water slurries or slips, ammonium salts for polar liquids, acids and bases to control pH, and oleic acid, tartaric acid, benzoic acid, stearic acid, and trichloroacetic acid for oxide powders in nonpolar liquids. Surfactants are used in slurry processing to aid dispersion, and antifoams are used to remove trapped gas bubbles from the slurry.

### 2.2.4 Forming

In the forming step, dry powders, plastic bodies, pastes, or slurries are consolidated and molded to produce a cohesive body of the desired shape and size. Dry forming consists of the simultaneous compacting and shaping of dry ceramic powders in a rigid die or flexible mold. Dry forming can be accomplished by dry pressing, isostatic compaction, and vibratory compaction. In dry pressing, which is used for forming products that are of relatively uniform thickness and axially symmetric, ceramic powder with a moisture content of 5 to 15 percent is compacted between plungers in a die cavity. In isostatic compaction, ceramic powder with a moisture content of 0 to 15 percent is placed inside a flexible mold, which is then deaired, sealed, and placed in a gas- or liquid-filled pressurized chamber. Isostatic compaction is used to produce complex shapes such as spark plugs and

larger shapes that are not easily dry pressed. Vibratory compaction is used for producing irregular shapes from ungranulated powders.

Plastic molding is accomplished by extrusion, jiggering, or powder injection molding. Extrusion, which generally is preceded by mixing in a pugmill and deairing in a vacuum chamber, consists of consolidating plastic material with a moisture content of 12 to 20 percent, forcing it through a forming die, and ejecting the formed body. Extrusion is used in manufacturing structural clay products and some refractory products. Jiggering involves shaping a plastic clay body on a spinning porous plaster mold using a water mist or steam lubricated shaping tool. Jiggering is widely used in the manufacture of small, simple, axially symmetrical whiteware ceramic such as cookware, fine china, and electrical porcelain. In powder injection molding, a hot ceramic and binder mixture is injected into a cooler die, extracted, and deburred. This method is used for making small complex shapes.

Paste forming consists of applying a thick film of ceramic paste on a substrate. Ceramic pastes are used for decorating ceramic tableware, and forming capacitors and dielectric layers on rigid substrates for microelectronics.

Slurry forming of ceramics generally is accomplished using slip casting, gelcasting, or tape casting. In slip casting, a ceramic slurry, which has a moisture content of 20 to 35 percent, is poured into a porous mold. Capillary suction of the mold draws the liquid from the mold, thereby consolidating the cast ceramic material. After a fixed time, the excess slurry is drained, and the cast is dried. The casting rate can be increased by vacuum casting, heating, or centrifugal casting. Slip casting is widely used in the manufacture of sinks and other sanitaryware, figurines, porous thermal insulation, fine china, and structural ceramics with complex shapes. Gelcasting uses in situ polymerization of organic monomers to produce a gel that binds ceramic particles together into complex shapes such as turbine rotors. Tape casting consists of forming a thin film of ceramic slurry of controlled thickness onto a support surface using a knife edge. Tape casting is used to produce thin ceramic sheets or tape, which can be cut and stacked to form multilayer ceramics for capacitors and dielectric insulator substrates.

### 2.2.5 Green Machining

After forming, the ceramic shape often is machined to eliminate rough surfaces and seams or to modify the shape. The methods used to machine green ceramics include surface grinding to smooth surfaces, blanking and punching to cut the shape and create holes or cavities, and laminating for multilayer ceramics.

### 2.2.6 Drying

After forming, ceramics must be dried. Drying must be carefully controlled to strike a balance between minimizing drying time and avoiding differential shrinkage, warping, and distortion. The most commonly used method of drying ceramics is by convection, in which heated air is circulated around the ceramics. Air drying often is performed in tunnel kilns, which are long furnaces with drying, firing, and cooling zones. In tunnel kilns, the drying zone typically uses heat recovered from the cooling zone. Periodic kilns or dryers operating in batch mode also are used. Convection drying also is carried out in divided tunnel dryers, which include separate sections with independent temperature and humidity controls. An alternative to air drying is radiation drying in which microwave or infrared radiation is used to enhance drying.

### 2.2.7 Presinter Thermal Processing

Prior to firing, ceramics are often heat-treated at temperatures well below firing temperatures. The purpose of this thermal processing is to provide additional drying, to vaporize or decompose organic additives and other impurities, and to remove residual, crystalline, and chemically bound water. Presinter thermal processing can be applied as a separate step, which is referred to as bisque firing, or by gradually raising and holding the temperature in several stages.

Organic "burnout" typically occurs at a temperature of approximately half the firing temperature. Removal of residual liquid is attained at a temperature of approximately 200°C (392°F), water of crystallization is liberated at approximately 700°C (1290°F), and chemically bound water is eliminated at approximately 1000°C (1830°F).

### 2.2.8 Glazing

For traditional ceramics, glaze coatings often are applied to dried or bisque-fired ceramic ware prior to firing. Glazes, which resemble glass in structure and texture, provide a smooth, shiny surface that seals the ceramic body. Glazes consist primarily of oxides and can be classified as raw glazes or frit glazes. In raw glazes, the oxides are in the form of minerals or compounds that melt readily and act as solvents for the other ingredients. Some of the more commonly used raw materials for glazes are quartz, feldspars, carbonates, borates, and zircon. A frit is a prereacted glass. Frit manufacturing is addressed in AP-42 Section 11.14.

To prepare glazes, the raw materials are ground in a ball mill or attrition mill. Glazes generally are applied by spraying or dipping. Depending on their constituents, glazes mature at temperatures of 600° to 1500°C (1110° to 2730°F). Table 2-4 lists the compositions of several commercial glazes.

### 2.2.9 Firing

Firing is the process by which ceramics are thermally consolidated into a dense, cohesive body composed of fine, uniform grains. This process also is referred to as sintering or densification. The characteristics of unfired ceramics that most affect firing are particle size, density, and particle shape. In general: (1) ceramics with fine particle size fire quickly and require lower firing temperatures; (2) dense unfired ceramics fire quickly and remain dense after firing with lower shrinkage; and (3) irregular shaped ceramics fire quickly. Other material properties that affect firing include material surface energy, diffusion coefficients, fluid viscosity, and bond strength.

Parameters that affect firing include firing temperature, time, pressure, and atmosphere. Ceramics generally are fired at 50 to 75 percent of the absolute melting temperature of the material. Table 2-5 lists typical firing temperatures for several ceramic products. Firing occurs faster at higher temperatures, but so does coarsening. A short firing time results in a product that is porous and has a low density; short to intermediate firing time results in fine-grained (i.e., having particles not larger than 0.2 millimeters), high-strength products; and long firing times result in a coarse-grained products that are more creep resistant. Applying pressure decreases firing time and makes it possible to fire materials that are difficult to fire using conventional methods. Oxidizing or inert atmospheres are used to fire oxide ceramics to avoid reducing transition metals and degrading the finish of the product.

TABLE 2-4. COMPOSITIONS OF COMMERCIAL GLAZES<sup>a</sup>

Oxide	Glaze for hard paste porcelain	Glaze for soft paste porcelain	Sanitary ware glaze	Bristol glaze	Wall tile glaze	Semivitreous dinnerware glaze	Vitreous dinnerware glaze	Low expansion semi-crystalline glaze	Dinnerware glaze	Cone 06 dinnerware glaze	Opacified glaze	Zinc mat glaze
SiO <sub>2</sub>	78.00	73.83	59.71	67.09	62.25	59.09	55.79	53.91	55.88	42.45	44.07	33.31
Al <sub>2</sub> O <sub>3</sub>	13.24	14.32	18.58	13.01	10.36	13.53	7.37	26.98	9.57	7.04	15.04	15.99
B <sub>2</sub> O <sub>3</sub>					1.36	4.30	5.47	4.98	6.04	8.93	3.62	3.50
ZrO <sub>2</sub>							0.57			0.72	11.10	9.16
Li <sub>2</sub> O						0.51		9.08				
Na <sub>2</sub> O			2.05	1.98	6.54	1.81	1.81		3.06	2.46	2.50	1.91
K <sub>2</sub> O	3.67	4.96	3.12	3.01	1.47	3.92	2.71	5.05	1.72		2.84	1.73
MgO				2.57	0.16	0.96	0.62					1.38
CaO	5.10	6.89	11.15	7.16	7.67	11.76	9.16		7.65	3.09	8.29	3.02
ZnO			5.39	5.19	10.18		10.94				10.97	10.48
SrO						4.12	3.07					
BaO							2.50				1.56	
PbO									16.08	35.30		19.52

<sup>a</sup>Reference 10. Numbers represent percent of the specified compound used in the manufacture of the specified glaze.

TABLE 2-5. TYPICAL FIRING TEMPERATURES OF CERAMICS<sup>a</sup>

Product	Firing temperature	
	°C	°F
<u>Pottery</u>		
Ceramic cooking pots	1120-1180	2050-2150
Flower pots	860-1010	1580-1850
Stoneware (chemical)	1450-1480	2650-2700
Stoneware (once fired)	1270-1330	2318-2426
Earthware or semi-vitreous ware-bisque	1250-1290	2282-2354
Earthware or semi-vitreous ware-glost	1190-1250	2174-2282
Artware-bisque	1010-1200	1850-2200
Artware-glost	980-1320	1800-2400
Pottery decalcomanias	700-820	1300-1500
<u>Whitewares:</u>		
Electrical porcelain	1150-1260	2100-2300
Hotel china-bisque	1200-1260	2200-2300
Sanitaryware-bisque	1200-1320	2200-2400
Hotel china-glost	1040-1230	1900-2250
Sanitaryware-glost	1230-1270	2246-2318
Floor tile	1150-1230	2100-2250
Wall tile-bisque	980-1200	1800-2200
Wall tile-glost	980-1230	1800-2250
<u>Porcelain enamels:</u>		
Wet process cast iron enamels	620-760	1150-1400
Dry process cast iron enamels	840-930	1550-1700
Sheet iron ground coat enamels	760-870	1400-1600
Sheet iron cover coat enamels	750-840	1380-1550
A-19 coating	860-880	1580-1620
Solaramic	930-1090	1700-2000
Aluminum	480-590	900-1100
<u>Electronic and newer ceramics:</u>		
Steatites	1260-1350	2300-2460
Aluminas	1540-1760	2800-3200
Titanates	1290-1370	2350-2500
Ferrites	1200-1450	2190-2650
Beryllia	Up to 1870	Up to 3400
Rare earths	1370-2200	2500-4000
Cermets	1590-1700	2900-3100

<sup>a</sup>Reference 7.

In addition to conventional firing, other methods used include pressure firing, hot forging, plasma firing, microwave firing, and infrared firing. The following paragraphs describe conventional and pressure firing, which are the methods used most often.

Conventional firing is accomplished by heating the green ceramic to approximately two-thirds of the melting point of the material at ambient pressure and holding it for a specified time in a kiln. Kilns can be classified as periodic (intermittent) or tunnel (continuous). Periodic kilns are heated and cooled according to prescribed schedules. The heat for periodic kilns generally is provided by electrical element or by firing with gas or oil. Periodic kilns can be classified as shuttle kilns, in which the kiln is fixed and the ceramics loaded on rails are run into the kiln for firing, and elevator kilns, in which the kiln is lowered onto the kiln car or the kiln car is lowered into the kiln for firing.

Tunnel kilns are long refractory chambers with constant temperature zones through which kiln cars are passed to provide the specified time-temperature cycle. Tunnel kilns generally have separate zones for cooling, firing, and preheating or drying. The kilns may be designed so that (1) the air heated in the cooling zone moves into the firing zone and the combustion gases in the firing zone are conveyed to the preheat/drying zone then exhausted, or (2) the air heated in the cooling zone is conveyed to the preheat/drying zone and the firing zone gases are exhausted separately. The most commonly used tunnel kiln design is the roller hearth (roller) kiln. In conventional firing, tunnel kilns generally are fired with gas, oil, coal, or wood.

Advanced ceramics often are fired in electric resistance-heated furnaces with controlled atmospheres. For some products, separate furnaces may be needed to eliminate organic lubricants and binders prior to firing.

Ceramic products also are manufactured by pressure firing, which is similar to the forming process of dry pressing except that the pressing is conducted at the firing temperature. The application of pressure enhances the densification of the ceramic during firing. Because of its higher costs, pressure firing is usually reserved for manufacturing ceramics that are difficult to fire to high density by conventional firing. In hot pressing, hydraulic presses and graphite dies commonly are used. In hot isostatic pressing, the pressing medium typically is a gas, such as argon or nitrogen.

#### 2.2.10 Final Processing

Following firing, some ceramic products are processed further to enhance their characteristics or to meet dimensional tolerances. Ceramics can be machined by abrasive grinding, chemical polishing, electrical discharge machining, or laser machining. Annealing at high temperature, followed by gradual cooling can relieve internal stresses within the ceramic and surface stresses due to machining. Ceramics that are oxygen sensitive often are annealed in a controlled atmosphere to achieve the stoichiometry that optimizes properties. Oxidation can increase the strength of certain hot-pressed ceramics. Flame polishing is sometimes used to reduce surface flaws. In addition, surface coatings are applied to many fired ceramics. Surface coatings are applied to traditional clay ceramics to create a stronger, impermeable surface and for decoration. Coatings also may be applied to improve strength and resistance to abrasion and corrosion. Coatings can be applied dry, as slurries, by spraying, or by vapor deposition.

## 2.3 EMISSIONS<sup>1,3-5,12-13</sup>

The primary pollutants associated with raw material beneficiation are particulate matter (PM) and PM less than 10 $\mu$ m in aerodynamic diameter (PM-10). Particulate matter is emitted from raw material crushing, grinding, screening, classifying, handling, transfer, and storage. In addition, raw material calciners emit filterable and condensable PM, which may include metals and other inorganic pollutants. In addition, calciners emit products of combustion such as nitrogen oxides (NO<sub>x</sub>), sulfur oxides (SO<sub>x</sub>), carbon monoxide (CO), carbon dioxide (CO<sub>2</sub>), and volatile organic compounds (VOC). Emissions of SO<sub>x</sub> are a function of the sulfur content of the fuel used to fire the calciners and the sulfur content of the raw materials used to manufacture ceramics. Emissions of VOC result from incomplete combustion and volatilization of the organic material in the raw material. Other beneficiation processes that are associated with emissions include acid leaching and granulation. Emissions of hydrochloric acid (HCl) or other acids may arise from leaching. In addition, products of combustion are emitted from spray dryers used for granulation.

Mixing generally is a wet process. However, VOC emissions from this step may arise from the volatilization of binders, plasticizers, and lubricants. Forming generally is performed in sealed containers and often is a wet process; emissions from this step in the process are likely to be negligible. For ceramic bodies that are dry-formed, PM is likely to be emitted from grinding, punching, and other green machining activities.

Particulate matter emissions consisting of metal and mineral oxides also arise from glaze preparation, which includes mixing and grinding. Emissions of PM from glaze application also are likely, if the glaze is applied by spraying.

Emissions associated from green ceramic heat treating processes, which include drying, presinter thermal processing, and firing, include combustion products and filterable and condensable PM. Particulate matter emissions consist, in part, of metals and the inorganic minerals associated with the raw materials. Emissions of the products of combustion are a function of fuel type, raw material constituents, process temperature, and other operating parameters.

Emissions of fluorine compounds also are associated with firing. Fluorine is present in ceramic raw materials in the range of 0.01 to 0.2 percent. As the temperature of the green ceramic bodies reaches 500° to 600°C (930° to 1110°F), the fluorine in the raw material forms hydrogen fluoride (HF) and other fluorine compounds such as silicon tetrafluoride. Much of the fluorine is released as HF. However, if lime is present in the ceramic body, HF reacts with the lime to form calcium fluoride (CaF<sub>2</sub>), thereby reducing potential HF emissions. Other factors that reduce fluorine emissions from ceramic kilns are listed in Table 2-6.

Other emission sources associated with ceramics manufacturing include final processing operations and fugitive dust sources. The final processing steps include grinding and polishing, which can emit PM and PM-10, and surface coating, annealing, and chemical treatment, which can emit VOC. Fugitive dust sources, which consist of vehicular traffic, wind erosion of storage piles, and materials handling and transfer, emit PM and PM-10.

## 2.4 EMISSION CONTROL TECHNOLOGY<sup>12-19</sup>

Several techniques have been used to control PM emissions from the mechanical processing of ceramic raw materials and finished products. Fabric filters are the commonly used control device, but wet scrubbers and electrostatic precipitators (ESP's) also have been used. Fabric filters, wet scrubbers,

TABLE 2-6. FACTORS THAT REDUCE HF EMISSIONS<sup>a</sup>

Factor	Process control technology
Body chemistry	Use of high lime raw materials or lime additions
Body and setting density	Employ higher density of body or setting pattern
Atmospheric water	Use of low hydrogen content fuels
Preheating rate	Increase above dehydroxylation temperature
Soak temperature	Reduce to a minimum
Vitrification	Increase through use of sintering aids
Soak duration	Reduce to a minimum
Kiln draft	Reduce to a minimum
Kiln exhaust temperature	Reduce to a minimum

<sup>a</sup>Reference 13.

and ESP's also are used to control emissions from clay calciners and dryers. Venturi scrubbers and fabric filters are used to control emissions from granulation (spray dryers) and from glaze preparation and application. Afterburners have been used to control VOC emissions from tape casting operations. Emissions from kilns generally are uncontrolled.

Table 2-6 lists process modifications that can be used to reduce HF emissions from kilns in the ceramic manufacturing industry. Dry sorption scrubbing also has been used in the brick and ceramic industries in Germany and in the brick industry in the U.S. to control emissions of HF. These devices use limestone as a sorption medium to produce  $\text{CaF}_2$ , which is removed by means of a rotating screen, drum, or fabric filter. Control efficiencies of 95 to 99 percent have been reported for this type of scrubber.

#### REFERENCES FOR SECTION 2

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### 3. GENERAL DATA REVIEW AND ANALYSIS PROCEDURES

#### 3.1 LITERATURE SEARCH AND SCREENING

Data for this investigation were obtained from a number of sources within the Office of Air Quality Planning and Standards (OAQPS) and from outside organizations. The AP-42 background files located in the Emission Factor and Inventory Group (EFIG) files were reviewed for information on the industry, processes, and emissions. The Factor Information and Retrieval (FIRE), Crosswalk/Air Toxic Emission Factor Data Base Management System (XATEF), and VOC/PM Speciation Data Base Management System (SPECIATE) data bases were searched by SCC code for identification of the potential pollutants emitted and emission factors for those pollutants. A general search of the Air CHIEF CD-ROM also was conducted to supplement the information from these data bases.

Information on the industry, including number of plants, plant location, and annual production capacities, was obtained from the *Census of Manufactures* and other sources. The Aerometric Information Retrieval System (AIRS) data base also was searched for data on the number of plants, plant location, and estimated annual emissions of criteria pollutants. A number of sources of information were investigated specifically for emission test reports and data. A search of the Test Method Storage and Retrieval (TSAR) data base was conducted to identify test reports for sources within the ceramic products manufacturing industry. Copies of these test reports were obtained from the files of the Emissions, Monitoring, and Analysis Division (EMAD). The EPA library was searched for additional test reports. Using information obtained on plant locations, State and Regional offices were contacted about the availability of test reports. Publications lists from the Office of Research and Development (ORD) and Control Technology Center (CTC) were also searched for reports on emissions from the ceramic products manufacturing industry. In addition, representative trade associations, including the Tile Council of America, the Ceramic Manufacturers' Association, and the American Ceramic Society, were contacted for assistance in obtaining information about the industry and emissions.

To screen out unusable test reports, documents, and information from which emission factors could not be developed, the following general criteria were used:

1. Emission data must be from a primary reference:
  - a. Source testing must be from a referenced study that does not reiterate information from previous studies.
  - b. The document must constitute the original source of test data. For example, a technical paper was not included if the original study was contained in the previous document. If the exact source of the data could not be determined, the document was eliminated.
2. The referenced study should contain test results based on more than one test run. If results from only one run are presented, the emission factors must be down rated.
3. The report must contain sufficient data to evaluate the testing procedures and source operating conditions (e.g., one-page reports were generally rejected).

A final set of reference materials was compiled after a thorough review of the pertinent reports, documents, and information according to these criteria.

### 3.2 DATA QUALITY RATING SYSTEM<sup>1</sup>

As part of the analysis of the emission data, the quantity and quality of the information contained in the final set of reference documents were evaluated. The following data were excluded from consideration:

1. Test series averages reported in units that cannot be converted to the selected reporting units;
2. Test series representing incompatible test methods (i.e., comparison of EPA Method 5 front half with EPA Method 5 front and back half);
3. Test series of controlled emissions for which the control device is not specified;
4. Test series in which the source process is not clearly identified and described; and
5. Test series in which it is not clear whether the emissions were measured before or after the control device.

Test data sets that were not excluded were assigned a quality rating. The rating system used was that specified by EFIG for preparing AP-42 sections. The data were rated as follows:

A—Multiple tests that were performed on the same source using sound methodology and reported in enough detail for adequate validation. These tests do not necessarily conform to the methodology specified in EPA reference test methods, although these methods were used as a guide for the methodology actually used.

B—Tests that were performed by a generally sound methodology but lack enough detail for adequate validation.

C—Tests that were based on an untested or new methodology or that lacked a significant amount of background data.

D—Tests that were based on a generally unacceptable method but may provide an order-of-magnitude value for the source.

The following criteria were used to evaluate source test reports for sound methodology and adequate detail:

1. Source operation. The manner in which the source was operated is well documented in the report. The source was operating within typical parameters during the test.
2. Sampling procedures. The sampling procedures conformed to a generally acceptable methodology. If actual procedures deviated from accepted methods, the deviations are well documented. When this occurred, an evaluation was made of the extent to which such alternative procedures could influence the test results.

3. Sampling and process data. Adequate sampling and process data are documented in the report, and any variations in the sampling and process operation are noted. If a large spread between test results cannot be explained by information contained in the test report, the data are suspect and are given a lower rating.

4. Analysis and calculations. The test reports contain original raw data sheets. The nomenclature and equations used were compared to those (if any) specified by EPA to establish equivalency. The depth of review of the calculations was dictated by the reviewer's confidence in the ability and conscientiousness of the tester, which in turn was based on factors such as consistency of results and completeness of other areas of the test report.

### 3.3 EMISSION FACTOR QUALITY RATING SYSTEM<sup>1</sup>

The quality of the emission factors developed from analysis of the test data was rated using the following general criteria:

A—Excellent: Developed only from A-rated test data taken from many randomly chosen facilities in the industry population. The source category is specific enough so that variability within the source category population may be minimized.

B—Above average: Developed only from A-rated test data from a reasonable number of facilities. Although no specific bias is evident, it is not clear if the facilities tested represent a random sample of the industries. The source category is specific enough so that variability within the source category population may be minimized.

C—Average: Developed only from A- and B-rated test data from a reasonable number of facilities. Although no specific bias is evident, it is not clear if the facilities tested represent a random sample of the industry. In addition, the source category is specific enough so that variability within the source category population may be minimized.

D—Below average: The emission factor was developed only from A- and B-rated test data from a small number of facilities, and there is reason to suspect that these facilities do not represent a random sample of the industry. There also may be evidence of variability within the source category population. Limitations on the use of the emission factor are noted in the emission factor table.

E—Poor: The emission factor was developed from C- and D-rated test data, and there is reason to suspect that the facilities tested do not represent a random sample of the industry. There also may be evidence of variability within the source category population. Limitations on the use of these factors are footnoted.

The use of these criteria is somewhat subjective and depends to an extent upon the individual reviewer. Details of the rating of each candidate emission factor are provided in Section 4.

#### REFERENCE FOR SECTION 3

1. *Technical Procedures for Developing AP-42 Emission Factors and Preparing AP-42 Sections*, EPA-454/B-93-050, Office of Air Quality Planning and Standards, U. S. Environmental Protection Agency, Research Triangle Park, NC, October 1993.

## 4. AP-42 SECTION DEVELOPMENT

### 4.1 INTRODUCTION

This section describes how the revised AP-42 section on ceramic products manufacturing was developed. First, descriptions of data sets reviewed for this revision are presented, followed by a discussion of how candidate emission factors were developed from the data. Finally, the proposed changes to the existing AP-42 section on ceramic clay manufacturing are summarized.

### 4.2 REVIEW OF SPECIFIC DATA SETS

A total of 33 references were obtained for use in developing emission factors for ceramic products manufacturing. References 14, 29, and 30 through 33 were not used for emission factor development. Reference 14 was not used because the process tested was a plastics manufacturing process rather than a ceramics process. Reference 29 was not used because it does not contain a process description or process data, and Reference 30 does not contain any original test data. References 31 through 33 were not used because they do not contain sufficient process data for emission factor development.

#### 4.2.1 Reference 1

This reference consists of a technical journal article and includes a brief description of ceramic floor and wall tile manufacturing, a discussion of emissions and controls, and a table of emission factors for several emission sources associated with the industry.

Emission factors are presented for uncontrolled and controlled emissions of PM, fluorine, and lead from raw material processing, glaze milling, and ceramic tile bisque-firing and firing. The article does not identify the type of control device on which the controlled emission factors are based. However, typical control devices are identified by source, and it is assumed that the controlled factors represent emissions controlled with the typical control devices listed.

The article states that the emission factors are based on the results of "thousands of measurements" over a 7-year period, but does not provide details on specific emission tests. The factors are presented in units of grams emitted per square meter ( $\text{g}/\text{m}^2$ ) of tile produced; the text explains that 1  $\text{m}^2$  of tile weighs 20 kilograms (kg). Using this conversion, the emission factors were calculated in units of kg per megagram (kg/Mg) and pounds per ton (lb/ton). Table 4-1 summarizes these emission factors from the article. Because this is a secondary reference with little documentation, the data are not rated for use in developing emission factors.

#### 4.2.2 Reference 2

This report documents measurements of uncontrolled filterable PM and fluoride emissions from a small natural gas-fired roller kiln used to refire ceramics after application of decals, paint, or ink screenings. This type of kiln maintains low operating temperatures and short product residence times. The test was conducted in March 1989 to demonstrate compliance with State regulations. Process rates were provided on the basis of production.

TABLE 4-1. SUMMARY OF EMISSION FACTORS FROM REFERENCE 1<sup>a</sup>

Source	Uncontrolled						Controlled <sup>b</sup>					
	PM		Fluorine		Lead		PM		Fluorine		Lead	
	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton
Raw material preparation and forming	2	4					0.16	0.32				
Bisque firing	0.05	0.1					0.02	0.04				
— High porosity ware			0.07	0.14					0.01	0.02		
— Medium porosity ware			0.13	0.26					0.015	0.03		
— Colored low porosity ware			0.16	0.32					0.02	0.04		
— Light color low porosity ware			0.43	0.85					0.035	0.07		
Glaze milling and glazing	1	2			0.2	0.4	0.07	0.14			0.025	0.05
Glost firing												
— Slow	0.1	0.2	0.05	0.1	0.01	0.02	0.035	0.07	0.01	0.02	0.003	0.005
— Fast	0.06	0.12	0.03	0.06	0.008	0.015	0.015	0.03	0.005	0.01	0.001	0.002
Single firing--slow	0.1	0.2			0.015	0.03	0.025	0.05			0.003	0.005
— Colored low porosity ware			0.16	0.32					0.02	0.04		
— Light color low porosity ware			0.43	0.85					0.035	0.07		
Single firing--fast	0.06	0.12			0.01	0.02	0.02	0.04			0.001	0.002
— Colored low porosity ware			0.05	0.1					0.01	0.02		
— Light color low porosity ware			0.13	0.25					0.015	0.03		

<sup>a</sup>All emission factors in units of kg/Mg and lb/ton of tile produced. Data are not rated.

<sup>b</sup>Emissions from glaze milling and glazing controlled with venturi scrubbers; emissions from other sources controlled with fabric filter.

Filterable PM emissions were measured using Method 5, and fluoride emissions were measured using Kentucky Bureau of Environmental Protection Method 130, which is equivalent to EPA Method 13B. Three test runs were conducted. In addition, CO<sub>2</sub> concentrations were measured by Orsat and reported for the three test runs. Emission factors were developed for emissions of filterable PM, fluoride, and CO<sub>2</sub> from the kiln. The emission data are rated B. The test methodology was sound, and no problems were reported. However, because the report included no details on the process, and process rates were estimated rather than measured during the test, a higher rating is not warranted.

#### 4.2.3 Reference 3

This report documents measurements of uncontrolled filterable PM and fluoride emissions from a natural gas-fired kiln used to manufacture ceramic tile. The test was conducted at the same facility discussed in Reference 2, but was conducted on a different kiln. The test was performed in April 1989 to demonstrate compliance with State regulations. Process rates were provided on the basis of production.

Filterable PM emissions were measured using Method 5, and fluoride emissions were measured using Kentucky Bureau of Environmental Protection Method 130. Three test runs were conducted. Emission factors were developed for emissions of filterable PM and fluoride from the kiln. The emission data are rated B. The test methodology was sound, and no problems were reported. However, because the report included no details on the process, and process rates were estimated rather than measured during the test, a higher rating is not warranted.

#### 4.2.4 Reference 4

This report documents measurements of uncontrolled filterable PM, fluoride, and SO<sub>2</sub> emissions from a gas-fired kiln used to manufacture ceramic bricks. The test was conducted in September 1993 to demonstrate compliance with local regulations. Process rates were provided on the basis of production.

The process consists of forming bricks from a clay blend, spraying a color pigment on the outside surface, drying the bricks to a moisture content of 5 to 6 percent, then firing the bricks in a tunnel kiln at a temperature of 1120°C (2050°F). A kiln cycle, the time for the bricks to exit the kiln from the time they enter kiln, was 73 hours.

Filterable PM emissions were measured using Method 5, fluoride emissions were measured using Method 13B, and Method 6 was used to measure SO<sub>2</sub> emissions. Three test runs were conducted. In addition, CO<sub>2</sub> concentrations were measured by Orsat and reported for the three test runs. Emission factors were developed for emissions of filterable PM, fluoride, SO<sub>2</sub>, and CO<sub>2</sub> from the kiln. The emission data are rated B. The test methodology was sound, and no problems were reported. However, these data are not used for emission factor development in this section because they are representative of structural clay product manufacturing, which is addressed in AP-42 Section 11.3.

#### 4.2.5 Reference 5

This report documents measurements of uncontrolled filterable PM, fluoride, SO<sub>2</sub>, and NO<sub>x</sub> emissions from a gas-fired tunnel kiln. The test was conducted in November 1993 to demonstrate compliance with local regulations.

The facility operates three tunnel kilns and produces unglazed ceramic tile. During the test, the kiln sampled was firing tile composed of a mixture of 40 percent clay and 60 percent shale. The average sulfur content of the unfired tile was 0.064 percent. Process rates were based on the average rate of fired tile produced.

Filterable PM emissions were measured using Method 5, fluoride emissions were measured using Method 13A, SO<sub>2</sub> emissions were measured using Method 6C, and NO<sub>x</sub> emissions were quantified using Method 7E. Three test runs were conducted. In addition, CO<sub>2</sub> concentrations were measured by Orsat and reported for the three test runs. According to the observer from the local air pollution control agency, the SO<sub>2</sub> measurements were not valid due to equipment problems during the test. However, the major problem appears to be the way in which the post-test calibration was conducted. Also, the test firm had difficulty with the pretest calibration.

Emission factors were developed for emissions of filterable PM, fluoride, NO<sub>x</sub>, and CO<sub>2</sub> from the kiln. The emission data are rated B, except for the SO<sub>2</sub> data, which are rated C because of the calibration problems. The test methodology was sound, but the report lacked adequate details on the process to warrant a higher rating.

#### 4.2.6 Reference 6

This report documents measurements of uncontrolled filterable PM, fluoride, and SO<sub>2</sub> emissions from three gas-fired tunnel kilns ducted to a common stack. The test was conducted in March and April of 1994 to demonstrate compliance with local regulations.

The facility tested is the same plant for which an emission test was documented in Reference 5. At the time of the test documented in Reference 5, the three kilns were ducted to separate stacks. However, prior to the test documented in this reference, the exhausts for all three kilns were ducted to the same stack. During the test, two of the kilns were firing tile formed from 100 percent clay, and the other kiln was firing tile composed of a mixture of 30 percent clay and 70 percent shale. The average raw material sulfur content during the month of the test was 0.11 percent. Process rates were based on the average rate of fired tile produced.

Filterable PM emissions were measured using Method 5, fluoride emissions were measured using Method 13A, and SO<sub>2</sub> emissions were measured using Method 6. Three test runs were conducted. In addition, CO<sub>2</sub> concentrations were measured by Orsat and reported for six test runs. Emission factors were developed for emissions of filterable PM, fluoride, SO<sub>2</sub>, and CO<sub>2</sub> from the kiln. The emission data are rated B. The test methodology was sound, and no problems were reported. However, the report lacked adequate details on the process to warrant a higher rating.

#### 4.2.7 Reference 7

This report documents measurements of uncontrolled filterable PM, fluoride, SO<sub>2</sub>, and NO<sub>x</sub> emissions from a gas-fired tunnel kiln. The test was conducted in August 1993 to demonstrate compliance with local regulations.

The kiln tested was a fast fire roller hearth design tunnel kiln. The kiln includes a preheat section that uses excess heat from the kiln, a firing section, and a cooling section. Emissions from the preheating and firing sections are ducted to one stack, and the emissions from the cooling section of the kiln are ducted to a separate stack. At the time of the test the facility was producing ceramic wall tile. The materials used in the process included talc, clay, wollastonite, and pyrophyllite. The average raw material sulfur content from May through June, 1993, was 0.0089 percent. Because the same type of ceramic was produced during testing, this sulfur content is assumed to be similar to the average sulfur content during testing. Process rates were based on the average rate of fired tile produced.

Filterable PM emissions were measured using Method 5, fluoride emissions were measured using Method 13A, SO<sub>2</sub> emissions were measured using Method 6, and NO<sub>x</sub> emissions were quantified using Method 7E. Three test runs were conducted. In addition, CO<sub>2</sub> concentrations were measured by Orsat and reported for the three test runs.

Emission factors were developed for emissions of filterable PM, fluoride, SO<sub>2</sub>, NO<sub>x</sub>, and CO<sub>2</sub> from the kiln. The emission data are rated B. The test methodology was sound, and no problems were reported. However, the report lacked adequate details on the process to warrant a higher rating.

#### 4.2.8 Reference 8

This report documents measurements of controlled filterable PM emissions from a first crushing and screening line used in the manufacture of ceramic tile. The test was conducted in October 1991 to demonstrate compliance with local regulations. Process rates were provided on the basis of production.

The line tested processes raw material, and PM emissions generated from the process are controlled with a fabric filter. The exhaust from the fabric filter then is discharged to the atmosphere through a stack.

Filterable PM emissions were measured using Method 5. Three 60-minute test runs were conducted. Emission factors were developed for emissions of filterable PM from the process. The emission data are rated B. The test method was sound, and no problems were reported. However, only average process rates were reported.

#### 4.2.9 Reference 9

This report documents measurements of controlled filterable PM emissions from a crushing and screening line used in the manufacture of ceramic tile. The facility was the same facility discussed in Reference 8, but a different processing line was sampled during this test. The test was conducted in October 1991 to demonstrate compliance with local regulations. Process rates were provided on the basis of production.

The crushing and screening line processes both raw material and grog (calcined fire clay). Emissions from the line are controlled with two fabric filters, one for body material and one for grog. The exhaust from the fabric filters is then combined and discharged to the atmosphere through a single stack. The test was conducted downstream from the point where the two exhaust streams combine.

Filterable PM emissions were measured using Method 5. Three 60-minute test runs were conducted. Emission factors were developed for emissions of filterable PM from the process. The emission data are rated B. The test method was sound, and no problems were reported. However, only average process rates were reported.

#### 4.2.10 Reference 10

This report documents measurements of controlled TOC emissions from ceramic tape casters. The test was conducted in September 1989 to demonstrate compliance with local regulations.

The facility operates two tape casters, followed by a gas-fired fume oxidizer (incinerator) for emission control. Solvents used in the process include toluene and methyl isobutyl ketone. The vapors are captured by a series of hoods and associated duct work and conveyed to the incinerator. Process rates were based on production.

Total organic compound (referred to as VOC in the summary data tables and in AP-42) emissions were measured using Method 25A. Five test runs were conducted, but the first was void due to an upset condition. Analysis of the samples collected during Run 2 indicated that the process may not have reached steady state during the time of the test run. During Run 5, the process rate dropped considerably and the results of the run are questionable. Therefore, only runs 2 and 3 were used for emission factor development. An emission factor was developed for emissions of VOC (as propane). Because only two valid test runs were conducted, the emission data are assigned a rating of B.

#### 4.2.11 Reference 11

This report documents measurements of uncontrolled filterable PM, HF, SO<sub>2</sub>, NO<sub>x</sub>, CO, TOC (referred to as VOC in the summary data tables and in AP-42), and CO<sub>2</sub> emissions from two gas-fired kilns, one dryer, and one cooler. The test was conducted in April 1994 to demonstrate compliance with local regulations.

The facility tested operates two kilns and produces ceramic saddles and spheres (used in scrubbers) for the chemical industry. A clay/water mixture is extruded and cut, loaded into ceramic or metal containers, and put onto pallets which are conveyed through a dryer operating at 127°C (260°F). After drying, the pallets are slowly passed through four zones of the kiln as the operating temperature increases from 704° to 1148°C (1300° to 2100°F). The total cure time varies from 24 to 37 hours. The finished product is then cooled and packaged for shipping.

The kiln exhaust flows through the dryer and the moist, warm gas exits the dryer at the rear through a stack. Emissions tests were performed on the main stacks for both kilns, the dryer exhaust for Kiln No. 1, and the cooler exhaust for Kiln No. 2. Process rates were based on the feed rates to the kilns.

Filterable PM emissions were measured using Method 5, HF emissions were measured using Method 13A, to measure SO<sub>2</sub> emissions Method 6C was used, NO<sub>x</sub> emissions were quantified using Method 7E, CO emissions were measured using Method 10, and VOC (as propane) emissions were measured by Method 25A. In addition, CO<sub>2</sub> concentrations were measured by Orsat and reported. Three test runs were conducted for each source tested.

Emission factors were developed for emissions of filterable PM, HF, NO<sub>x</sub>, SO<sub>2</sub>, CO, VOC (as propane), and CO<sub>2</sub> from the kilns. Emission factors were developed for emissions of filterable PM from the dryer and cooler. The emission data are rated B. The test methods were sound, and no problems were reported. However, only average process rates were reported.

#### 4.2.12 Reference 12

This report documents measurements of controlled TOC emissions from a ceramic furnace. The test was conducted in August 1993 to demonstrate compliance with local regulations.

The facility produces circuit board components that are made of multilayer ceramic sheets, which are cut from prefired ceramic tape, plated, pressed, and cured. The source tested was an electric furnace that is used to cure the ceramic circuit parts. Organic binders, solvents, and plasticizers are used in the process.

A normal curing cycle lasts 24 hours and consists of four stages. Volatile organic compounds and other evaporative substances volatilize during the first 5 hours (the binder burnout stage), as the temperature in the furnace is gradually raised from 20° to 900°C (68° to (1652°F). During the subsequent 7-hour period, the temperature in the furnace is gradually raised to 1350°C (2462°F), then held constant for another 7-hour period. Finally, the product is cooled for 5 hours. All of the exhaust gases vented through the stack are ignited with a natural gas flare.

The normal process weight is 12 lb/cycle. However, during the test a 36 lb charge was cured in the furnace.

Total organic compound emissions were measured using Method 25A, and three test runs were conducted. The runs spanned three of the 5 hours of the binder burnout stage, but it is unclear what portion of total VOC for the cycle was emitted during the 3-hour sampling period. During the first two runs, the TOC concentrations fluctuated between 2.6 and 3.6 ppm as carbon. However, a spike in exhaust stream TOC concentrations (84 ppm as carbon) occurred near the end of the third run, and the TOC concentrations were still elevated (25 ppm as carbon) when the run ended.

Emission factors were developed for emissions of TOC from the process by assuming that all TOC were emitted over 5 hours at the average TOC emission rate for the three runs. Because the emission measurements were made over only a relatively small span of the entire kiln cycle, and because there is inadequate information for making an accurate estimate of total TOC emissions from the furnace cycle, the emission data are rated D.

#### 4.2.13 Reference 13

This report documents measurements of controlled filterable PM emissions from a spray dryer. The test was conducted in March 1993 to demonstrate compliance with local regulations. Process rates were provided on the basis of production.

The facility manufacturers electronic ceramics, toner carrier for copier machines, and cerium carbonate. The source tested was the spray dryer on the electronic ceramics manufacturing line. Ferrite powder, organic binder, and water are mixed, pelletized, and calcined. After cooling, the material is wet-ground into a slurry, then dried in the spray dryer, which is heated by natural gas. Hot, moist air exiting the spray dryer passes through a cyclone and fabric filter for ferrite powder removal. The exhaust from the fabric filter is then discharged to the atmosphere.

Filterable PM emissions were measured using Method 5. Three test runs were conducted and emission factors were developed for emissions of filterable PM from the process. The emission data are rated A.

#### 4.2.14 Reference 15

This reference is an inspection report made for the purpose of renewing the annual certificate of operation for the facility from Reference 12. Although the report is not a primary reference for emission data, it includes a process description and provides supplemental information on the facility.

#### 4.2.15 Reference 16

This reference is an inspection report made for the purpose of renewing certificates of operation for the facility from Reference 13. Although the report is not a primary reference for emission data, it includes a process description and provides supplemental information on the facility.

#### 4.2.16 Reference 17

This reference is an inspection report made for the purpose of renewing certificates of operation for the facility from Reference 11. Although the report is not a primary reference for emission data, it includes a process description and provides supplemental information on the facility.

#### 4.2.17 Reference 18

This report documents measurements of filterable PM emissions from two spray booths used in a ceramic glaze line. Emissions from the spray booths were controlled with a wet scrubber. The test was conducted in August 1992, to demonstrate compliance with State regulations. Filterable PM emissions were measured using Method 5, and three test runs were conducted. Correspondence received from the Ohio EPA provided the process rate as the average tons of glaze used per hour.

The emission data are rated B. The test methodology was sound, and no problems were reported. However, since the process rate was provided as a daily average, a higher rating is not warranted.

#### 4.2.18 Reference 19

This report documents measurements of filterable PM emissions from two spray booths used in a ceramic spray line. Emissions from the spray booths were controlled with a wet scrubber. The test was conducted in August 1992, to demonstrate compliance with State regulations. Filterable PM emissions were measured using Method 5, and three test runs were conducted. Correspondence received from the Ohio EPA provided the process rate as the average tons of glaze used per hour.

The emission data are rated B. The test methodology was sound, and no problems were reported. However, since the process rate was provided as a daily average, a higher rating is not warranted.

#### 4.2.19 Reference 20

This report documents measurements of filterable PM emissions from two spray booths used in a ceramic glaze line. Emissions from the spray booths were controlled with a wet scrubber. The test was conducted in February 1994, to demonstrate compliance with State regulations. Filterable PM emissions were measured using Method 5, and three test runs were conducted. The process rate was provided as the average tons of glaze used per hour.

The emission data are rated B. The test methodology was sound, and no problems were reported. However, since the process rate was provided as a daily average, a higher rating is not warranted.

#### 4.2.20 Reference 21

This report documents measurements of uncontrolled filterable PM and fluoride emissions from a direct-, natural gas-fired roller kiln. The kiln was firing ceramic tile during the test program. The test was conducted in May 1994, to demonstrate compliance with State regulations. Process rates were provided on the basis of production.

Filterable PM and total fluoride emissions were measured using a combined EPA Method 5 and Method 13B sampling train. Three test runs were conducted and emission factors were developed for emissions of filterable PM and total fluorides from the process. The emission data are rated A.

#### 4.2.21 Reference 22

This reference (excerpts from a test report) documents measurements of uncontrolled filterable PM and fluoride emissions from a direct-, natural gas-fired roller kiln (same kiln as that described in Reference 21). The kiln was firing ceramic tile during the test program. The test was conducted in June 1993, to demonstrate compliance with State regulations. An average process rate was provided on the basis of production.

The test was conducted by the same firm that conducted the test described in Reference 21, and the procedures and test methods are assumed to be identical. Three test runs were conducted and emission factors were developed for emissions of filterable PM and fluorides from the process. The emission data are rated C because only excerpts of the actual test report are available, and the process rate is a daily average.

#### 4.2.22 Reference 23

This reference (excerpts from a test report) documents measurements of uncontrolled filterable PM and fluoride emissions from a direct-, natural gas-fired roller kiln (same kiln as that described in Reference 21). The kiln was firing ceramic tile during the test program. The test was conducted in February 1992, to demonstrate compliance with State regulations. An average process rate was provided on the basis of production.

The test was conducted by the same firm that conducted the test described in Reference 21, and the procedures and test methods are assumed to be identical. Three test runs were conducted and emission factors were developed for emissions of filterable PM and fluorides from the process. The emission data are rated C because only excerpts of the actual test report are available and the process rate is a daily average.

#### 4.2.23 Reference 24

This report documents measurements of venturi scrubber-controlled filterable PM emissions from a natural gas-fired spray dryer. The dryer is part of a ceramic body preparation plant. The test was conducted in October 1994, to demonstrate compliance with State regulations. An average process rate was provided on the basis of production.

Filterable PM emissions were measured using EPA Method 5. Three test runs were conducted and emission factors were developed for emissions of filterable PM from the process. The emission data are rated B because scrubber operating parameters are not provided in the report.

#### 4.2.24 Reference 25

This reference (excerpts from a test report) documents measurements of venturi scrubber-controlled filterable PM emissions from a natural gas-fired spray dryer (same dryer as that described in Reference 24). The test was conducted in April 1994, to demonstrate compliance with State regulations. An average process rate was provided on the basis of production.

The test was conducted by the same firm that conducted the test described in Reference 24, and the procedures and test methods are assumed to be identical. Three test runs were conducted and emission factors were developed for emissions of filterable PM from the process. The emission data are rated C because only excerpts of the actual test report are available, the process rate is a daily average, and scrubber operating parameters are not provided.

#### 4.2.25 Reference 26

This reference (excerpts from a test report) documents measurements of venturi scrubber-controlled filterable PM emissions from a natural gas-fired spray dryer (same dryer as that described in Reference 24). The test was conducted in January 1993, to demonstrate compliance with State regulations. An average process rate was provided on the basis of production.

The test was conducted by the same firm that conducted the test described in Reference 24, and the procedures and test methods are assumed to be identical. Three test runs were conducted and emission factors were developed for emissions of filterable PM from the process. The emission data are rated C because only excerpts of the actual test report are available, the process rate is a daily average, and scrubber operating parameters are not provided.

#### 4.2.26 Reference 27

This reference (excerpts from a test report) documents measurements of venturi scrubber-controlled filterable PM emissions from a natural gas-fired spray dryer (same dryer as that described in Reference 24). The test was conducted in February 1992, to demonstrate compliance with State regulations. An average process rate was provided on the basis of production.

The test was conducted by the same firm that conducted the test described in Reference 24, and the procedures and test methods are assumed to be identical. Three test runs were conducted and emission factors were developed for emissions of filterable PM from the process. The emission data are rated C because only excerpts of the actual test report are available, the process rate is a daily average, and scrubber operating parameters are not provided.

#### 4.2.27 Reference 28

This report documents measurements of uncontrolled filterable PM and lead emissions from a ceramic spray booth. The spray booth used a lead-based glaze to coat ceramic tile during the test program. The test was conducted in September 1989, to demonstrate compliance with State regulations. An average process rate was provided on the basis of tons of glaze used per hour.

Filterable PM and lead emissions were measured using a combined EPA Method 5 and Method 12 sampling train. Three test runs were conducted and emission factors were developed for emissions of filterable PM and lead from the process. The emission data are rated A.

### 4.3 DEVELOPMENT OF CANDIDATE EMISSION FACTORS

Tables 4-2 and 4-3 summarize the test data from References 1 through 13 and 18 through 28, and Tables 4-4 and 4-5 present the candidate emission factors for ceramic products manufacturing. Emission factors were developed for firing--natural gas-fired kiln, refiring--natural gas-fired kiln, comminution--raw material crushing and screening, forming--tape casting, dryers, coolers, granulation--natural gas-fired spray dryers, and ceramic glaze spray booths. The emission factors were developed by grouping data from similar combinations of source, pollutant, and control device, discarding the inferior data sets, and averaging the emission factors derived from each data set.

Emission data for natural gas-fired kilns were available for a variety of ceramic products and types of kilns. However, because most of the test reports include little information on raw material composition and kiln operating parameters, there is little basis for grouping data sets according to how these parameters affect emissions. Therefore, in most cases, data for different types of kilns and products are grouped together to develop average emission factors. For CO, CO<sub>2</sub>, and NO<sub>x</sub>, this approach appears reasonable because these emissions result primarily from fuel combustion. For filterable PM, this approach appears reasonable because the data for different products and kilns overlapped to a large extent. Fluoride and HF emissions are directly related to the raw material fluorine content, but the test reports do not document the raw material fluorine content. Therefore, the fluoride data are averaged together, and the HF data are averaged together.

One data set was separated by raw material type. The emission factors for SO<sub>2</sub> are separated by raw material sulfur content (documented in three of the four test reports), which is a primary source of SO<sub>2</sub> emissions from ceramic kilns. In addition, data for emissions from ceramic refiring kilns were grouped separately because an industry representative indicated that these kilns are not similar to other kilns used in the industry. The following paragraphs describe how the data presented in Tables 4-2 and -3 were used to develop the emission factors presented in Tables 4-4 and -5.

#### 4.3.1 Filterable PM

An emission factor for uncontrolled filterable PM emissions from natural gas-fired kilns was developed using A-rated data from one test, B-rated data from five tests, and C-rated data from three

TABLE 4-2. SUMMARY OF TEST DATA FOR CERAMIC KILNS<sup>a</sup>

Product	Pollutant	No. of runs	Data rating	kg/Mg			lb/ton			Ref. No.
				Minimum	Maximum	Average	Minimum	Maximum	Average	
Ceramic tile	Filterable PM	3	C	0.25	0.34	0.30	0.50	0.69	0.59	3
Ceramic tile	Fluoride	3	B	0.70	0.99	0.86	1.4	2.0	1.7	3
Glazed structural clay tile	Filterable PM	3	B	0.71	1.0	0.86	1.4	2.0	1.7	4
Glazed structural clay tile	Fluoride	3	B	0.31	0.32	0.32	0.62	0.65	0.64	4
Glazed structural clay tile	SO <sub>2</sub>	3	B	3.6	4.1	3.9	7.1	8.2	7.7	4
Glazed structural clay tile	CO <sub>2</sub>	3	B	340	370	360	680	740	710	4
Unglazed ceramic tile	Filterable PM	3	B	0.13	0.15	0.14	0.25	0.29	0.27	5
Unglazed ceramic tile	Fluoride	3	B	0.31	0.34	0.32	0.62	0.69	0.65	5
Unglazed ceramic tile	SO <sub>2</sub>	3	C	0.31	0.33	0.32	0.61	0.67	0.65	5
Unglazed ceramic tile	NO <sub>x</sub>	3	B	0.42	0.52	0.47	0.83	1.0	0.95	5
Unglazed ceramic tile	CO <sub>2</sub>	3	B	650	650	650	1,300	1,300	1,300	5
Unglazed ceramic tile	Filterable PM	3	B	0.49	0.74	0.59	1.0	1.5	1.2	6
Unglazed ceramic tile	Fluoride	3	B	0.14	0.17	0.16	0.28	0.33	0.31	6
Unglazed ceramic tile	SO <sub>2</sub>	3	B	2.4	2.4	2.4	4.7	4.8	4.8	6
Unglazed ceramic tile	CO <sub>2</sub>	6	B	70	160	140	130	320	280	6
Ceramic wall tile <sup>b</sup>	Filterable PM	3	B	0.023	0.031	0.028	0.046	0.063	0.055	7
Ceramic wall tile <sup>b</sup>	Fluoride	3	B	0.019	0.048	0.036	0.037	0.097	0.072	7
Ceramic wall tile <sup>b</sup>	SO <sub>2</sub>	3	B	0.035	0.046	0.039	0.070	0.092	0.078	7
Ceramic wall tile <sup>b</sup>	NO <sub>x</sub>	3	B	0.14	0.15	0.14	0.29	0.30	0.29	7
Ceramic wall tile <sup>b</sup>	CO <sub>2</sub>	3	B	100	110	100	190	220	200	7
Ceramic saddles/spheres	Filterable PM	3	B	0.16	0.20	0.19	0.32	0.42	0.38	11
Ceramic saddles/spheres	HF	3	B	0.17	0.22	0.20	0.34	0.44	0.39	11
Ceramic saddles/spheres	SO <sub>2</sub>	3	B	0.49	0.54	0.51	0.98	1.1	1.0	11

TABLE 4-2. (continued)

Product	Pollutant	No. of runs	Data rating	kg/Mg			lb/ton			Ref. No.
				Minimum	Maximum	Average	Minimum	Maximum	Average	
Ceramic saddles/spheres	NO <sub>x</sub>	3	B	0.17	0.27	0.21	0.34	0.53	0.41	11
Ceramic saddles/spheres	CO	3	B	1.6	4.0	2.4	3.3	8.0	4.9	11
Ceramic saddles/spheres	VOC as propane <sup>c</sup>	3	B	0.15	0.23	0.19	0.31	0.45	0.38	11
Ceramic saddles/spheres	CO <sub>2</sub>	1	C	NA	NA	600	NA	NA	1,200	11
Ceramic saddles/spheres	Filterable PM	3	B	0.43	0.44	0.43	0.85	0.88	0.86	11
Ceramic saddles/spheres	HF	3	B	0.23	0.28	0.26	0.45	0.56	0.52	11
Ceramic saddles/spheres	SO <sub>2</sub>	3	B	2.7	3.6	3.3	5.4	7.2	6.5	11
Ceramic saddles/spheres	NO <sub>x</sub>	3	B	0.24	0.25	0.24	0.48	0.50	0.49	11
Ceramic saddles/spheres	CO	3	B	0.50	1.6	0.88	1.0	3.2	1.8	11
Ceramic saddles/spheres	VOC as propane <sup>c</sup>	3	B	0.19	0.27	0.24	0.38	0.54	0.48	11
Ceramic saddles/spheres	CO <sub>2</sub>	1	B	450	460	460	890	910	900	11
Electronic circuit boards	VOC as propane <sup>c</sup>	3	D	6.4	51	22	13	100	43	12
Ceramic tile <sup>b</sup>	Filterable PM	3	A	0.039	0.039	0.039	0.078	0.079	0.078	21
Ceramic tile <sup>b</sup>	Fluoride	3	A	0.031	0.048	0.040	0.031	0.096	0.080	21
Ceramic tile <sup>b</sup>	Filterable PM	3	C	0.019	0.058	0.040	0.038	0.12	0.079	22
Ceramic tile <sup>b</sup>	Fluoride	3	C	0.0085	0.060	0.039	0.017	0.12	0.078	22
Ceramic tile <sup>b</sup>	Filterable PM	3	C	0.024	0.041	0.032	0.048	0.081	0.065	23
Ceramic tile <sup>b</sup>	Fluoride	3	C	0.023	0.095	0.054	0.045	0.19	0.11	23

<sup>a</sup>For firing green ceramics. Emission factors represent uncontrolled emissions unless noted; emission factors in units of kg/Mg and lb/ton of fired ceramic produced.

<sup>b</sup>Emission factor represents emissions from a roller kiln.

<sup>c</sup>VOC measured using EPA Method 25A. Emission factor may include nonphotochemically reactive compounds that are not considered VOC.

TABLE 4-3. SUMMARY OF TEST DATA FOR OTHER CERAMIC PRODUCTS MANUFACTURING SOURCES<sup>a</sup>

Source	Product	APCD <sup>b</sup>	Pollutant	No. of runs	Data rating	Emission factor, kg/Mg			Emission factor, lb/ton			Ref. No.
						Minimum	Maximum	Average	Minimum	Maximum	Average	
Ceramic refiring kiln	Ceramic tile <sup>c</sup>	None	Filterable PM	3	B	0.031	0.039	0.034	0.062	0.077	0.067	2
Ceramic refiring kiln	Ceramic tile <sup>c</sup>	None	Fluoride	3	B	0.0042	0.012	0.0094	0.0083	0.025	0.019	2
Ceramic refiring kiln	Ceramic tile <sup>c</sup>	None	CO <sub>2</sub>	2	B	47	50	49	94	100	97	2
Crushing/screening	Ceramic wall tile	FF	Filterable PM	3	B	0.037	0.044	0.041	0.074	0.087	0.082	8
Crushing/screening	Ceramic wall tile	FF	Filterable PM	3	B	0.071	0.087	0.081	0.14	0.17	0.16	9
Tape casting	Ceramic tape	AB	VOC as propane <sup>d</sup>	2	B	28	30	29	57	59	58	10
Dryer	Ceramic saddles/spheres	None	Filterable PM	3	C	0.19	2.4	1.2	0.37	4.7	2.3	11
Cooler	Ceramic saddles/spheres	None	Filterable PM	3	B	0.037	0.083	0.055	0.074	0.17	0.11	11
Spray dryer	Electronic parts	FF	Filterable PM	3	B	0.010	0.051	0.030	0.020	0.10	0.060	13
Ceramic glaze spray booths <sup>c</sup>	ND	WS	Filterable PM	3	B	0.55	1.7	1.1	1.1	3.4	2.2	18
Ceramic glaze spray booths <sup>c</sup>	Basins and urinals	WS	Filterable PM	3	B	0.32	0.94	0.66	0.63	1.9	1.3	19
Ceramic glaze spray booths <sup>c</sup>	Toilet tanks	WS	Filterable PM	3	B	0.80	1.1	0.92	1.6	2.2	1.8	20
Spray dryer	Ceramic body preparation	VS	Filterable PM	3	B	0.074	0.12	0.10	0.15	0.24	0.20	24
Spray dryer	Ceramic body preparation	VS	Filterable PM	3	C	0.054	0.079	0.063	0.11	0.16	0.13	25

TABLE 4-3. (continued)

Source	Product	APCD <sup>b</sup>	Pollutant	No. of runs	Data rating	Emission factor, kg/Mg			Emission factor, lb/ton			Ref. No.
						Minimum	Maximum	Average	Minimum	Maximum	Average	
Spray dryer	Ceramic body preparation	VS	Filterable PM	3	C	0.068	0.18	0.11	0.14	0.36	0.22	26
Spray dryer	Ceramic body preparation	VS	Filterable PM	3	C	0.063	0.16	0.11	0.13	0.33	0.22	27
Ceramic glaze spray booth using lead-based glaze	Ceramic tile	None	Filterable PM	3	A	9.3	10	9.7	19	20	19	28
Ceramic glaze spray booth using lead-based glaze	Ceramic tile	None	Lead	3	A	1.4	1.6	1.5	2.9	3.2	3.0	28

<sup>a</sup>Emission factors in units of kg/Mg and lb/ton of material processed, unless noted.

<sup>b</sup>FF = fabric filter, AB = afterburner, WS = wet scrubber, VS = venturi scrubber, ND = no data available.

<sup>c</sup>Kiln is used for refiring tile after decals, paint, or ink screening are applied. Kiln maintains a relatively low temperature and products are refired for 35 to 45 minutes.

<sup>d</sup>VOC measured using EPA Method 25A. Emission factor may include non-photochemically reactive compounds that are not considered VOC.

<sup>e</sup>Emission factor units are kg/Mg and lb/ton of glaze used.

TABLE 4-4. EMISSION FACTOR SUMMARY FOR NATURAL GAS-FIRED CERAMIC KILNS<sup>a</sup>

Product	Pollutant	Number of kilns tested	Emission factor rating	Minimum, kg/Mg (lb/ton)	Maximum, kg/Mg (lb/ton)	Average emission factor, kg/Mg (lb/ton)	Reference numbers
Ceramic saddles/spheres	CO	2	D	0.88 (1.8)	2.4 (4.9)	1.6 (3.3)	11
Ceramic saddles/spheres, ceramic tile	CO <sub>2</sub>	5	D	100 (200)	650 (1300)	390 (780)	5-7,11
Ceramic saddles/spheres, ceramic tile	Filterable PM	7	D	0.028 (0.055)	0.59 (1.2)	0.25 (0.49)	3,5-7,11, 21-23
Ceramic tile	Fluoride	5	E	0.036 (0.072)	0.86 (1.7)	0.28 (0.56)	3,5-7, 21-23
Ceramic saddles/spheres, ceramic tile	HF	2	E	0.020 (0.39)	0.32 (0.65)	0.23 (0.46)	11
Ceramic saddles/spheres, ceramic tile	NO <sub>x</sub>	4	D	0.14 (0.29)	0.47 (0.95)	0.27 (0.54)	5-7,11
Ceramic tile (0.1% sulfur raw material)	SO <sub>2</sub>	1	E	NA	NA	2.1 (4.1)	6
Ceramic tile (<0.07% sulfur raw material)	SO <sub>2</sub>	2	E	0.039 (0.078) <sup>b</sup>	0.32 (0.65) <sup>c</sup>	4.7·S <sup>d</sup> (9.5·S)	7
Ceramic saddles/spheres	VOC as propane <sup>b</sup>	2	D	0.19 (0.38)	0.24 (0.48)	0.22 (0.43)	11

<sup>a</sup>Emission factors represent uncontrolled emissions; emission factor units are kg/Mg and lb/ton of fired ceramics produced.

NA = not applicable.

<sup>b</sup>Factor based on raw material with 0.0089 percent sulfur.

<sup>c</sup>Factor based on raw material with 0.064 percent sulfur.

<sup>d</sup>Where S is the raw material sulfur content (percent). English units equation derived as follows:  $S \cdot \left( \frac{0.078}{0.0089} + \frac{0.65}{0.064} \right)$

<sup>e</sup>VOC measured using EPA Method 25A. Emission factor may include nonphotochemically reactive compounds that are not considered VOC.

TABLE 4-5. EMISSION FACTOR SUMMARY FOR MISCELLANEOUS CERAMIC PRODUCTS  
MANUFACTURING SOURCES<sup>a</sup>

Source	Product	APCD <sup>b</sup>	Pollutant	No. of tests	Emission factor rating	Emission factor, kg/Mg (lb/ton)			Ref. No.
						Minimum	Maximum	Average	
Ceramic refiring kiln	Ceramic tile <sup>c</sup>	None	Filterable PM	1	E	NA	NA	0.034 (0.067)	2
Ceramic refiring kiln	Ceramic tile <sup>c</sup>	None	Fluoride	1	E	NA	NA	0.0094 (0.019)	2
Ceramic refiring kiln	Ceramic tile <sup>c</sup>	None	CO <sub>2</sub>	1	E	NA	NA	49 (97)	2
Crushing/screening	Ceramic wall tile	FF	Filterable PM	2	D	0.041 (0.082)	0.081 (0.16)	0.061 (0.12)	8,9
Tape casting	Ceramic tape	AB	VOC as propane <sup>d</sup>	1	E	NA	NA	29 (58)	10
Dryer	Ceramic saddles/spheres	None	Filterable PM	1	E	NA	NA	1.2 (2.3)	11
Cooler	Ceramic saddles/spheres	None	Filterable PM	1	E	NA	NA	0.055 (0.11)	11
Spray dryer	Electronic parts	FF	Filterable PM	1	E	NA	NA	0.030 (0.060)	13
Spray dryer	Misc. ceramics	VS	Filterable PM	4	D	0.063 (0.13)	0.11 (0.22)	0.096 (0.19)	24-27
Ceramic glaze spray booth <sup>e</sup>	Misc. ceramics	WS	Filterable PM	3	D	0.66 (1.3) <sup>e</sup>	1.1 (2.2) <sup>e</sup>	0.89 (1.8) <sup>e</sup>	18-20
Ceramic glaze spray booth <sup>f</sup>	Ceramic tile	None	Filterable PM	1	E	NA	NA	9.7 (19)	28
Ceramic glaze spray booth <sup>f</sup>	Ceramic tile	None	Lead	1	E	NA	NA	1.5 (3.0)	28

<sup>a</sup>Emission factor units are kg/Mg and lb/ton of material processed, unless noted. NA = not applicable.

<sup>b</sup>FF = fabric filter, AB = afterburner, WS = wet scrubber, VS = venturi scrubber.

<sup>c</sup>Kiln is used for refiring tile after decals, paint, or ink screenings are applied. Emission factor units are kg/Mg and lb/ton of fired ceramics produced.

<sup>d</sup>VOC measured using EPA Method 25A. Emission factor may include non-photochemically reactive compounds that are not considered VOC.

<sup>e</sup>Emission factor units are kg/Mg and lb/ton of glaze used.

<sup>f</sup>Lead-based glaze used during testing. Emission factor units are kg/Mg and lb/ton of glaze used. Glaze contained 24.1 percent lead oxide.

tests. The tests were conducted on seven kilns at six different facilities. The data from References 21 through 23 (same kiln) were averaged first and then were averaged with the other data. The data range from 0.028 to 0.59 kg/Mg (0.055 to 1.2 lb/ton) and average 0.25 kg/Mg (0.49 lb/ton). This candidate emission factor is assigned a D rating because it was developed using data that range over an order of magnitude.

An emission factor for filterable PM emissions from a natural gas-fired ceramic refiring kiln was developed using B-rated data from a single test. The emission factor is 0.034 kg/Mg (0.067 lb/ton). This candidate emission factor is assigned an E rating because it was developed using data from a single test.

An emission factor for filterable PM emissions from comminution (raw material crushing and screening) was developed using B-rated data from two tests conducted on two crushing and screening lines located at the same facility. Emissions from both lines were controlled by fabric filters. The data range from 0.041 to 0.081 kg/Mg (0.082 to 0.16 lb/ton) and average 0.061 kg/Mg (0.12 lb/ton). This candidate emission factor is assigned a D rating because it was developed using B-rated data from two tests conducted at the same facility.

An emission factor for uncontrolled filterable PM emissions from a dryer (heated with the exhaust from a natural gas-fired ceramic kiln firing ceramic saddles and spheres) was developed using C-rated data from a single test. The emission factor is 1.2 kg/Mg (2.3 lb/ton). This candidate emission factor is assigned an E rating because it was developed from C-rated data.

An emission factor for uncontrolled filterable PM emissions from a cooler (following a natural gas-fired ceramic kiln firing ceramic saddles and spheres) was developed using B-rated data from a single test. The emission factor is 0.055 kg/Mg (0.11 lb/ton). This candidate emission factor is assigned an E rating because it is based on data from a single test.

An emission factor for filterable PM emissions from spray dryers was developed using B-rated data from a single test. The spray dryer tested was controlled by a fabric filter. The emission factor is 0.030 kg/Mg (0.060 lb/ton). This candidate emission factor is assigned an E rating because it is based on data from a single test.

An emission factor for filterable PM emissions from spray dryers controlled with venturi scrubbers was developed using B-rated data from one test and C-rated data from three tests conducted on the same dryer. The data range from 0.063 kg/Mg (0.13 lb/ton) to 0.11 kg/Mg (0.22 lb/ton) and average 0.096 kg/Mg (0.19 lb/ton). This candidate emission factor is assigned a D rating because it was developed using data from a single dryer.

An emission factor for filterable PM emissions from ceramic glaze spray booths controlled with wet scrubbers was developed using B-rated data from three tests conducted on three different spray lines at the same facility. The emission factor units for these factors are kg/Mg (lb/ton) of glaze used. The data range from 0.66 kg/Mg (1.3 lb/ton) to 1.1 kg/Mg (2.2 lb/ton) and average 0.89 kg/Mg (1.8 lb/ton). This candidate emission factor is assigned a D rating because it was developed using data from a single facility.

An emission factor for filterable PM emissions from uncontrolled ceramic glaze spray booths was developed using A-rated data from a single test. The spray booth tested was using a lead-based glaze (24.1 percent lead oxide) during testing. The emission factor is 9.7 kg/Mg (19 lb/ton) of glaze

used. This candidate emission factor is assigned an E rating because it was developed using data from a single test.

#### 4.3.2 Volatile Organic Compounds

The VOC emission factors described below are based on EPA Method 25A measurements. Therefore, these factors actually represent total organic compounds and may include non-photochemically reactive compounds that are not considered VOC.

An emission factor for uncontrolled VOC (as propane) emissions from natural gas-fired kilns was developed using B-rated data from tests conducted on two kilns. The data range from 0.19 to 0.24 kg/Mg (0.38 to 0.48 lb/ton) and average 0.22 kg/Mg (0.43 lb/ton). This candidate emission factor is assigned a D rating because it was developed using data from two kilns located at the same facility.

An emission factor for uncontrolled VOC (as propane) emissions from electric ceramic furnaces (firing electronic circuit boards) was developed using the D-rated data presented in Reference 12. However, this emission factor is not rated and is not proposed as a candidate emission factor for the following reasons. The process entailed the manufacture of a specialty product in very small quantities (36 lb per kiln cycle): the kiln was operating at three times the normal process weight rate; and because of the fluctuations in emissions for the process, the emissions sampled are not likely representative of an entire kiln cycle.

An emission factor for VOC (as propane) emissions from ceramic tape casters was developed using B-rated data from a single test. The tape casters tested were controlled by an afterburner. The emission factor is 29 kg/Mg (58 lb/ton). This candidate emission factor is assigned a E rating because it was developed using data from a single test.

#### 4.3.3 Carbon Monoxide

An emission factor for uncontrolled CO emissions from natural gas-fired kilns was developed using B-rated data from tests conducted on two kilns. The data range from 0.88 to 2.4 kg/Mg (1.8 to 4.9 lb/ton) and average 1.6 kg/Mg (3.3 lb/ton). This candidate emission factor is assigned a D rating because it was developed using data from two kilns located at the same facility.

#### 4.3.4 Carbon Dioxide

An emission factor for uncontrolled CO<sub>2</sub> emissions from natural gas-fired kilns was developed using B-rated data from three tests and B- and C-rated data from two tests conducted at the same facility. The data range from 100 kg/Mg (200 lb/ton) to 650 kg/Mg (1,300 lb/ton) and average 300 kg/Mg (590 lb/ton). This candidate emission factor is assigned a D rating because it was developed using data from kilns located at only three facilities.

An emission factor for CO<sub>2</sub> emissions from natural gas-fired ceramic refiring kilns was developed using B-rated data from a single test. The emission factor is 49 kg/Mg (97 lb/ton). This candidate emission factor is assigned an E rating because it was developed using data from a single test.

#### 4.3.5 Nitrogen Oxides

An emission factor for uncontrolled NO<sub>x</sub> emissions from natural gas-fired kilns was developed using B-rated data from four tests, two of which were conducted on kilns located at the same facility. The data range from 0.14 to 0.47 kg/Mg (0.29 to 0.95 lb/ton) and average 0.27 kg/Mg (0.54 lb/ton). This candidate emission factor is assigned a D rating because it was developed using data from kilns located at only two facilities.

#### 4.3.6 Sulfur Dioxide

An emission factor for uncontrolled SO<sub>2</sub> emissions from natural gas-fired kilns firing ceramics with a raw material sulfur content of 0.11 percent was developed using B-rated data from a single test. The emission factor is 2.4 kg/Mg (4.8 lb/ton). In AP-42, this factor is presented as 22·S kg/Mg (44·S lb/ton), where S is the raw material sulfur content (percent). This factor is assumed to be applicable to facilities using raw material with a sulfur content greater than 0.07 percent. This candidate emission factor is assigned an E rating because it was developed using data from a single test. Data from two B-rated tests (Reference 11) are not used because of several inconsistencies in the documented raw material sulfur analysis.

An emission factor for uncontrolled SO<sub>2</sub> emissions from natural gas-fired kilns firing ceramics with a raw material sulfur content of less than or equal to 0.07 percent was developed using data from one B-rated test and one C-rated test. The emission factor, presented as an equation, is 4.7·S kg/Mg (9.5·S lb/ton), where S is the raw material sulfur content (percent). This factor is assumed to be applicable to facilities using raw material with a sulfur content less than or equal to 0.07 percent. This candidate emission factor is assigned an E rating because it was developed using B- and C-rated data from two tests.

#### 4.3.7 Hydrogen Fluoride

An emission factor for uncontrolled HF emissions from natural gas-fired kilns was developed using B-rated data from two tests conducted on two kilns located at a single facility. The data range from 0.20 to 0.32 kg/Mg (0.39 to 0.65 lb/ton) and average 0.23 kg/Mg (0.46 lb/ton). This candidate emission factor is assigned an E rating because it was developed using data from a single facility, and HF emissions vary widely by facility.

#### 4.3.8 Fluoride

An emission factor for fluoride emissions from natural gas-fired kilns was developed using A-rated data from one test, B-rated data from four tests, and C-rated data from two tests. The A- and C-rated tests were conducted on the same kiln, and these data were averaged first and then were averaged with the B-rated data. The data range from 0.036 kg/Mg (0.072 lb/ton) to 0.86 kg/Mg (1.7 lb/ton) and average 0.28 kg/Mg (0.56 lb/ton). This candidate emission factor is assigned an E rating because it was developed using data that range over an order of magnitude.

An emission factor for fluoride emissions from a natural gas-fired ceramic refiring kiln was developed using B-rated data from a single test. The emission factor is 0.0094 kg/Mg (0.019 lb/ton). This candidate emission factor is assigned an E rating because it was developed using data from a single test.

#### 4.3.9 Lead

An emission factor for lead emissions from uncontrolled ceramic glaze spray booths was developed using A-rated data from a single test. The spray booth tested was using a lead-based glaze (24.1 percent lead oxide) during testing. The emission factor is 1.5 kg/Mg (3.0 lb/ton) of glaze used. This candidate emission factor is assigned an E rating because it was developed using data from a single test.

### 4.4 SUMMARY OF CHANGES TO AP-42 SECTION

#### 4.4.1 Section Narrative

The process description was revised to reflect current industry practices and was expanded to present a more complete description of the ceramic products manufacturing industry. A process flow diagram also was added to the section based on the revised process description. In addition, emissions from ceramic product manufacturing operations and types of emission control systems currently in use are discussed. The previous version of this AP-42 section addressed the beneficiation of ceramic raw materials only. Because the revised section addresses the entire process of manufacturing ceramic products, the title of the AP-42 section also was changed to "Ceramic Products Manufacturing."

#### 4.4.2 Emission Factors

The emission factors in the current AP-42 section are not presented in the revised section because the background file did not contain any of the old AP-42 references. However, the publication dates (pre-1970) indicate that any data from these references are probably not useful for emission factor development. The candidate emission factors discussed in Section 4.3 of this report are presented in the revised AP-42 section. Based on current guidelines for rating emission factors, the new emission factors are assigned lower ratings (mostly "D-rated") than the "A-rated" factors previously presented in AP-42. However, the new factors are based on more reliable and representative test data. The SO<sub>2</sub>, fluoride, and HF emission factors are footnoted as being primarily dependent of the types of raw materials (and fuel for SO<sub>2</sub>) used at specific facilities.

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## 5. PROPOSED AP-42 SECTION 11.7

The proposed AP-42 Section 11.7, Ceramic Products Manufacturing, is presented on the following pages as it would appear in the document.