11.25 Clay Processing

11.25.1 Process Description[1-4]

Clay is defined as a natural, earthy, fine-grained material, largely of a group of crystalline hydrous silicate minerals known as clay minerals. Clay minerals are composed mainly of silica, alumina, and water, but they may also contain appreciable quantities of iron, alkalies, and alkaline earths. Clay is formed by the mechanical and chemical breakdown of rocks. The six-digit Source Classification Codes (SCC) for clay processing are as follows: SCC 3-05-041 for kaolin processing, SCC 3-05-042 for ball clay processing, SCC 3-05-043 for fire clay processing, SCC 3-05-044 for bentonite processing, SCC 3-05-045 for fuller's earth processing, and SCC 3-05-046 for common clay and shale processing.

Clays are categorized into six groups by the U. S. Bureau Of Mines. The categories are kaolin, ball clay, fire clay, bentonite, fuller's earth, and common clay and shale. Kaolin, or china clay, is defined as a white, claylike material composed mainly of kaolinite, which is a hydrated aluminum silicate ($Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$), and other kaolin-group minerals. Kaolin has a wide variety of industrial applications including paper coating and filling, refractories, fiberglass and insulation, rubber, paint, ceramics, and chemicals. Ball clay is a plastic, white-firing clay that is composed primarily of kaolinite and is used mainly for bonding in ceramic ware, primarily dinnerware, floor and wall tile, pottery, and sanitary ware. Fire clays are composed primarily of kaolinite, but also may contain several other materials including diaspore, burley, burley-flint, ball clay, and bauxitic clay and shale. Because of their ability to withstand temperatures of 1500°C (2700°F) or higher, fire clays generally are used for refractories or to raise vitrification temperatures in heavy clay products. Bentonite is a clay composed primarily of smectite minerals, usually montmorillonite, and is used largely in drilling muds, in foundry sands, and in pelletizing taconite iron ores. Fuller's earth is defined as a nonplastic clay or claylike material that typically is high in magnesia and has specialized decolorizing and purifying properties. Fuller's earth, which is very similar to bentonite, is used mainly as absorbents of pet waste, oil, and grease. Common clay is defined as a plastic clay or claylike material with a vitrification point below 1100°C (2000°F). Shale is a laminated sedimentary rock that is formed by the consolidation of clay, mud, or silt. Common clay and shale are composed mainly of illite or chlorite, but also may contain kaolin and montmorillonite.

Most domestic clay is mined by open-pit methods using various types of equipment, including draglines, power shovels, front-end loaders, backhoes, scraper-loaders, and shale planers. In addition, some kaolin is extracted by hydraulic mining and dredging. Most underground clay mines are located in Pennsylvania, Ohio, and West Virginia, where the clays are associated with coal deposits. A higher percentage of fire clay is mined underground than other clays, because the higher quality fire clay deposits are found at depths that make open-pit mining less profitable.

Clays usually are transported by truck from the mine to the processing plants, many of which are located at or near the mine. For most applications, clays are processed by mechanical methods, such as crushing, grinding, and screening, that do not appreciably alter the chemical or mineralogical properties of the material. However, because clays are used in such a wide range of applications, it is often necessary to use other mechanical and chemical processes, such as drying, calcining, bleaching, blunging, and extruding to prepare the material for use.

Primary crushing reduces material size from as much as one meter to a few centimeters in diameter and typically is accomplished using jaw or gyratory crushers. Rotating pan crushers, cone crushers, smooth roll crushers, toothed roll crushers, and hammer mills are used for secondary crushing, which further reduces particle size to 3 mm (0.1 in.) or less. For some applications, tertiary size reduction is necessary and is accomplished by means of ball, rod, or pebble mills, which are often combined with air separators. Screening typically is carried out by means of two or more multi-deck sloping screens that are mechanically or electromagnetically vibrated. Pug mills are used for blunging, and rotary, fluid bed, and vibrating grate dryers are used for drying clay materials. At most plants that calcine clay, rotary or flash calciners are used. However, multiple hearth furnaces often are used to calcine kaolin.

Material losses through basic mechanical processing generally are insignificant. However, material losses for processes such as washing and sizing can reach 30 to 40 percent. The most significant processing losses occur in the processing of kaolin and fuller’s earth. The following paragraphs describe the steps used to process each of the six categories of clay. Table 11.25-1 summarizes these processes by clay type.

Kaolin -

Kaolin is both dry- and wet-processed. The dry process is simpler and produces a lower quality product than the wet process. Dry-processed kaolin is used mainly in the rubber industry, and to a lesser extent, for paper filling and to produce fiberglass and sanitary ware. Wet-processed kaolin is used extensively in the paper manufacturing industry. A process flow diagram for kaolin mining and dry processing is presented in Figure 11.25-1, and Figure 11.25-2 illustrates the wet processing of kaolin.

In the dry process, the raw material is crushed to the desired size, dried in rotary dryers, pulverized and air-floated to remove most of the coarse grit. Wet processing of kaolin begins with blunging to produce a slurry, which then is fractionated into coarse and fine fractions using centrifuges, hydrocyclones, or hydroseparators. At this step in the process, various chemical methods, such as bleaching, and physical and magnetic methods, may be used to refine the material. Chemical processing includes leaching with sulfuric acid, followed by the addition of a strong reducing agent such as hydrosulfite. Before drying, the slurry is filtered and dewatered by means of a filter press, centrifuge, rotary vacuum filter, or tube filter. The filtered dewatered slurry material may be shipped or further processed by drying in apron, rotary, or spray dryers. Following the drying step, the kaolin may be calcined for use as filler or refractory material. Multiple hearth furnaces are most often used to calcine kaolin. Flash and rotary calciners also are used.

Ball Clay -

Mined ball clay, which typically has a moisture content of approximately 28 percent, first is stored in drying sheds until the moisture content decreases to 20 to 24 percent. The clay then is shredded in a disintegrator into small pieces 1.3 to 2.5 centimeters (cm) (0.5 to 1 in.) in thickness. The shredded material then is either dried or ground in a hammer mill. Material exiting the hammer mill is mixed with water and bulk loaded as a slurry for shipping. Figure 11.25-3 depicts the process flow for ball clay processing.

Indirect rotary or vibrating grate dryers are used to dry ball clay. Combustion gases from the firebox pass through an air-to-air heat exchanger to heat the drying air to a temperature of approximately 300°C (570°F). The clay is dried to a moisture content of 8 to 10 percent. Following drying, the material is ground in a roller mill and shipped. The ground ball clay may also be mixed with water as a slurry for bulk shipping.

Table 11.25-1. CLAY PROCESSING OPERATIONS

Process	Kaolin	Ball Clay	Fire Clay	Bentonite	Fuller's Earth	Common Clay And Shale
Mining	X	X	X	X	X	X
Stockpiling	X	X	X	X	X	X
Crushing	X	X	X	X	X	X
Grinding	X	X	X	X	X	X
Screening	X		X		X	X
Mixing	X	X				X
Blunging	X				X	X
Air flotation	X	X				
Slurrying	X	X				
Extruding					X	X
Drying	X		X	X	X	X
Calcining	X		X			
Packaging	X	X	X	X	X	
Other	Water fraction-ation, magnetic separation, acid treatment, bleaching	Shredding, pulverizing	Weathering, blending	Cation exchange, granulating, air classifying	Dispersing	

Fire Clay -

Figure 11.25-4 illustrates the process flow for fire clay processing. Mined fire clay first is transported to the processing plant and stockpiled. In some cases, the crude clay is weathered for 6 to 12 months, depending on the type of fire clay. Freezing and thawing break the material up, resulting in smaller particles and improved plasticity. The material then is crushed and ground. At this stage in the process, the clay has a moisture content of 10 to 15 percent. For certain applications, the clay is dried in mechanical dryers to reduce the moisture content of the material to 7 percent or less. Typically, rotary and vibrating grate dryers fired with natural gas or fuel oil are used for drying fire clay.

To increase the refractoriness of the material, fire clay often is calcined. Calcining eliminates moisture and organic material and causes a chemical reaction to occur between the alumina and silica in the clay, rendering a material (mullite) that is harder, denser, and more easily crushed than

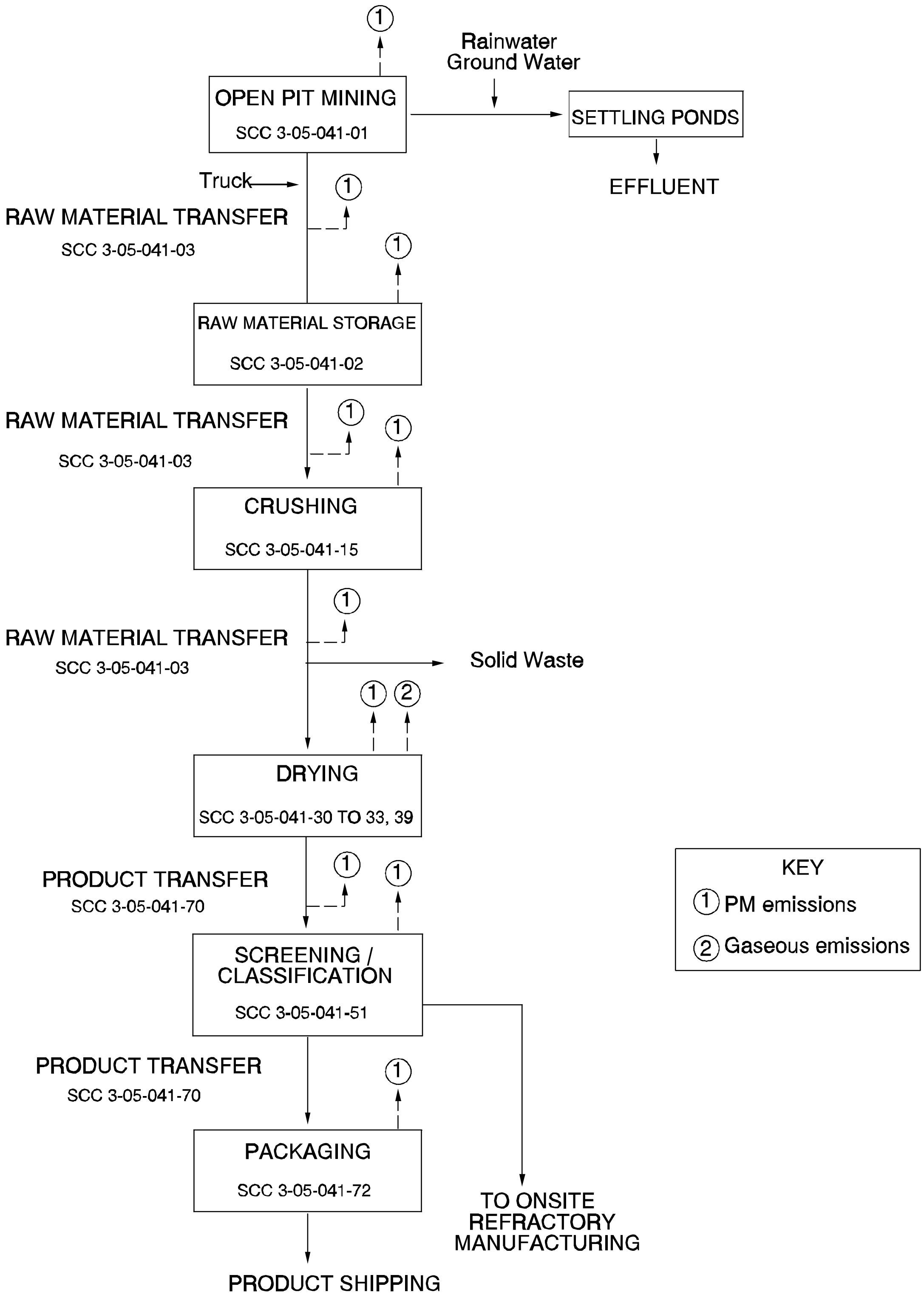

Figure 11.25-1. Process flow diagram for kaolin mining and dry processing.
(SCC = Source Classification Code.)

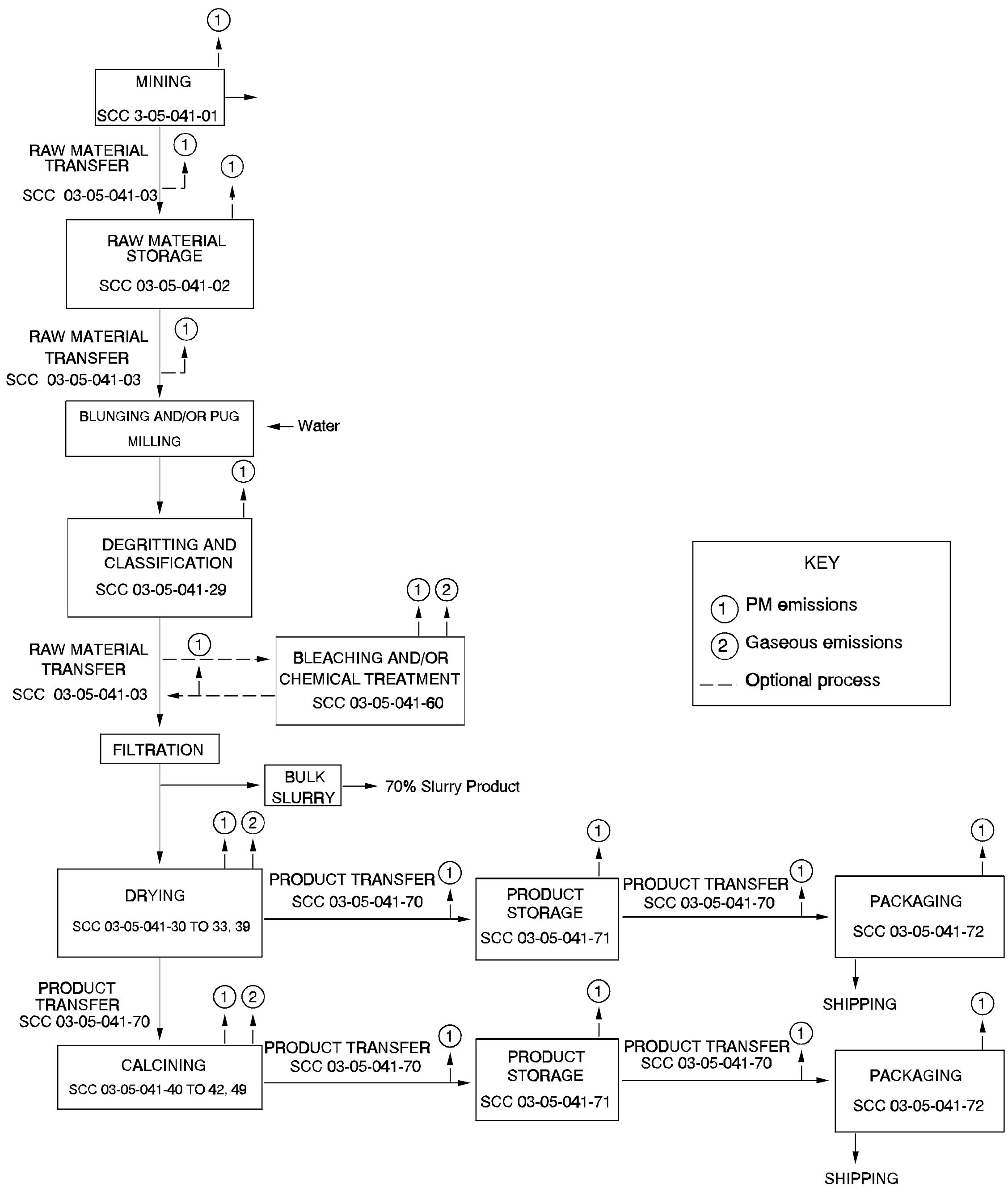

Figure 11.25-2. Process flow diagram for wet process kaolin for high grade products.
(SCC = Source Classification Code.)

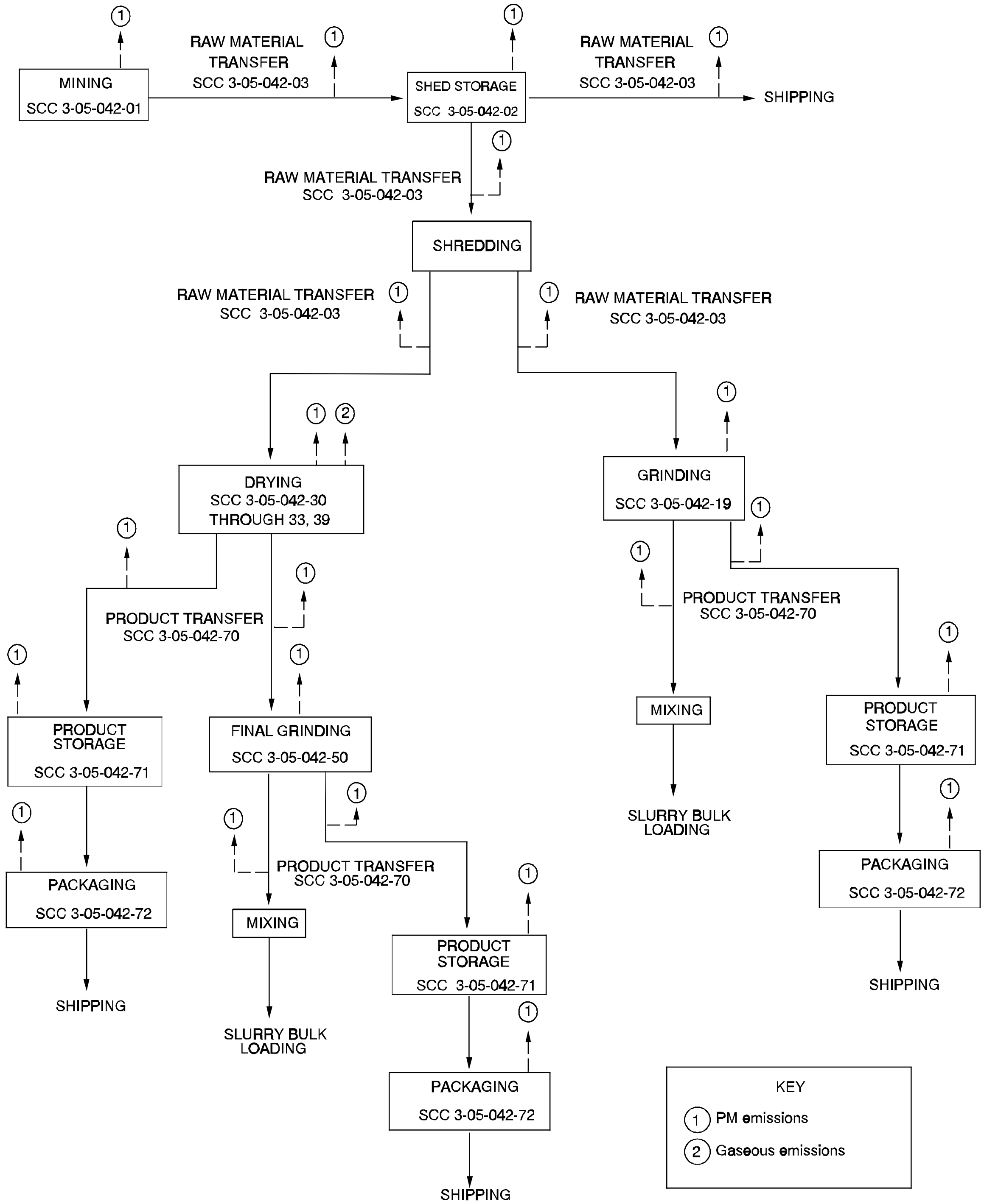

Figure 11.25-3. Process flow diagram for ball clay processing.
(SCC = Source Classification Code.)

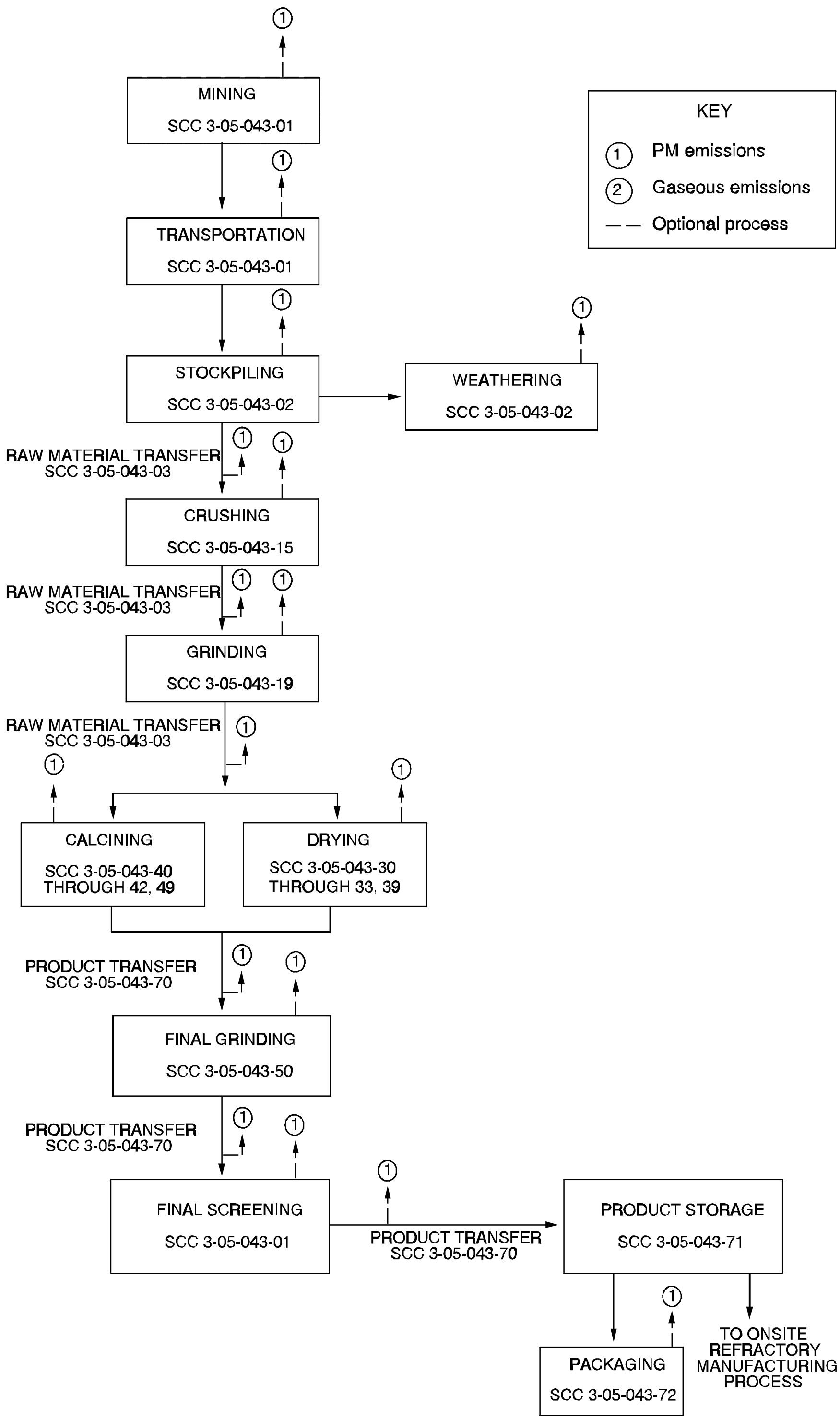

Figure 11.25-4. Process flow diagram for fire clay processing.
(SCC = Source Classification Code.)

uncalcined fire clay. After the clay is dried and/or calcined, the material is crushed, ground, and screened. After screening, the processed fire clay may be blended with other materials, such as organic binders, before to being formed in the desired shapes and fired.

Bentonite -

A flow diagram for bentonite processing is provided in Figure 11.25-5. Mined bentonite first is transported to the processing plant and stockpiled. If the raw clay has a relatively high moisture content (30 to 35 percent), the stockpiled material may be plowed to facilitate air drying to a moisture content of 16 to 18 percent. Stockpiled bentonite may also be blended with other grades of bentonite to produce a uniform material. The material then is passed through a grizzly and crusher to reduce the clay pieces to less than 2.5 cm (1 in.) in size. Next, the crushed bentonite is dried in rotary or fluid bed dryers fired with natural gas, oil, or coal to reduce the moisture content to 7 to 8 percent. The temperatures in bentonite dryers generally range from 900°C (1650°F) at the inlet to 100 to 200°C (210 to 390°F) at the outlet. The dried material then is ground by means of roller or hammer mills. At some facilities which produce specialized bentonite products, the material is passed through an air classifier after being ground. Soda ash also may be added to the processed material to improve the swelling properties of the clay.

Fuller's Earth -

A flow diagram for fuller's earth processing is provided in Figure 11.25-6. After being mined, fuller's earth is transported to the processing plant, crushed, ground, and stockpiled. Before drying, fuller's earth is fed into secondary grinders to reduce further the size of the material. At some plants, the crushed material is fed into a pug mill, mixed with water, and extruded to improve the properties needed for certain end products. The material then is dried in rotary or fluid bed dryers fired with natural gas or fuel oil. Drying reduces the moisture content to 0 to 10 percent from its initial moisture content of 40 to 50 percent. The temperatures in fuller's earth dryers depend on the end used of the product. For colloidal grades of fuller's earth, drying temperatures of approximately 150°C (300°F) are used, and for absorbent grades, drying temperatures of 650°C (1200°F) are typical. In some plants, fuller's earth is calcined rather than dried. In these cases, an operating temperature of approximately 675°C (1250°F) is used. The dried or calcined material then is ground by roller or hammer mills and screened.

Common Clay And Shale -

Figure 11.25-7 depicts common clay and shale processing. Common clay and shale generally are mined, processed, formed, and fired at the same site to produce the end product. Processing generally begins with primary crushing and stockpiling. The material then is ground and screened. Oversize material may be further ground to produce particles of the desired size. For some applications, common clay and shale are dried to reduce the moisture content to desired levels. Further processing may include blunging or mixing with water in a pug mill, extruding, and firing in a kiln, depending on the type of end product.

11.25.2 Emissions And Controls[3,9-10]

The primary pollutants of concern in clay processing operations are particulate matter (PM) and PM less than 10 micrometers (PM-10). Particulate matter is emitted from all dry mechanical processes, such as crushing, screening, grinding, and materials handling and transfer operations. The emissions from dryers and calciners include products of combustion, such as carbon monoxide (CO), carbon dioxide (CO_2), nitrogen oxides (NO_x), and sulfur oxides (SO_x), in addition to filterable and condensible PM. Volatile organic compounds associated with the raw materials and the fuel also may be emitted from drying and calcining.

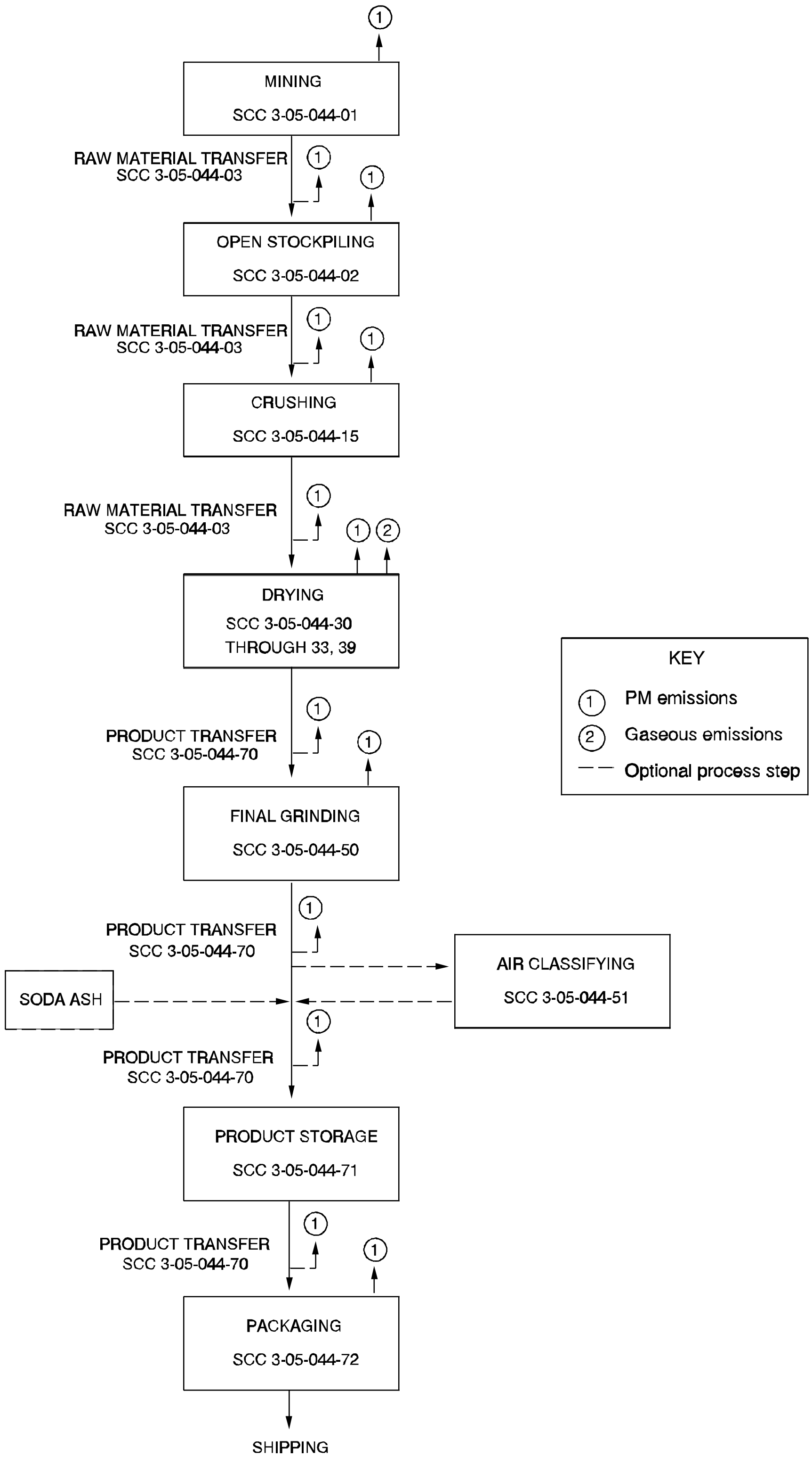

Figure 11.25-5. Process flow diagram for bentonite processing.
(SCC = Source Classification Code.)

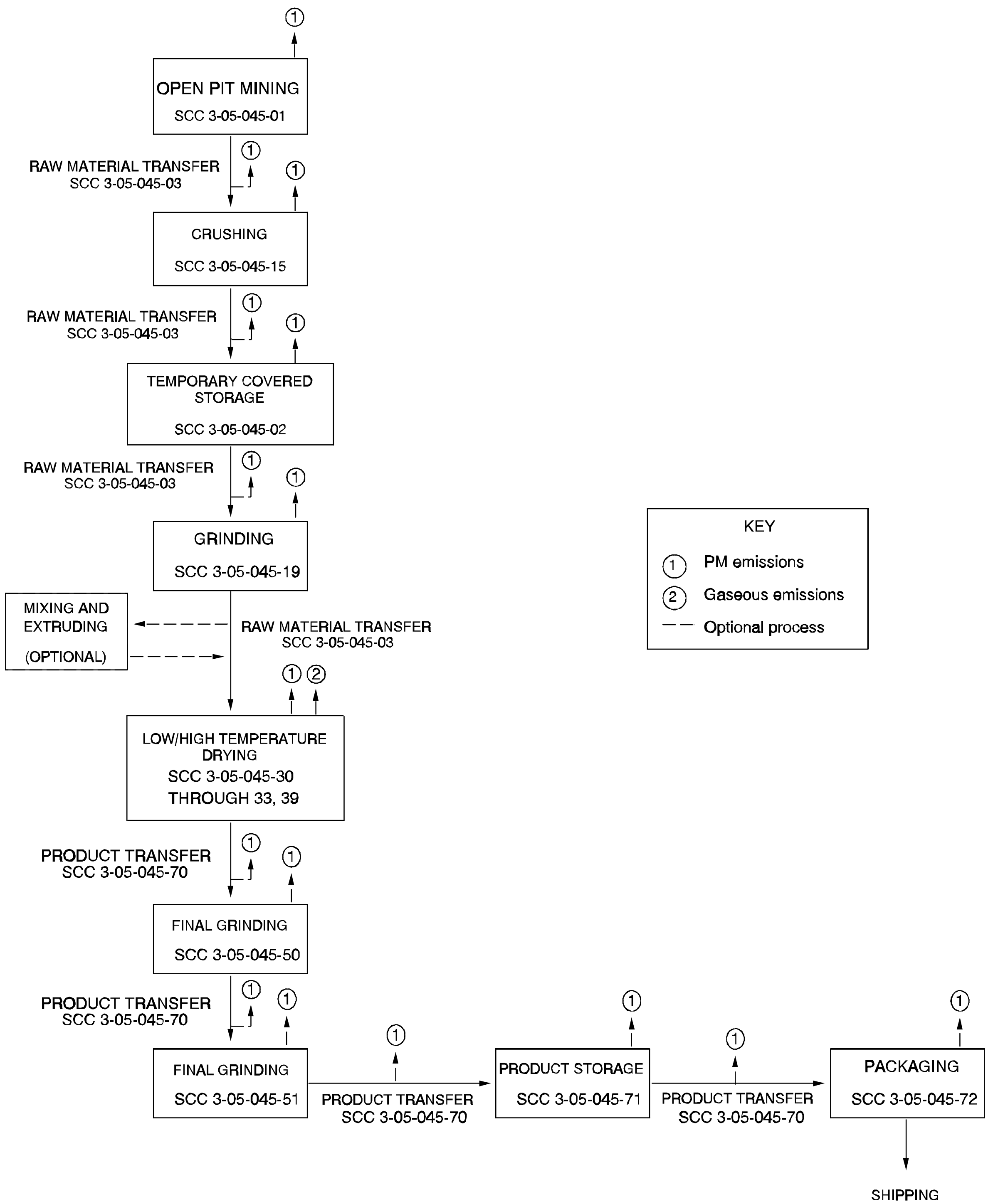

Figure 11.25-6. Process flow diagram for fuller's earth processing.
(SCC = Source Classification Code.)

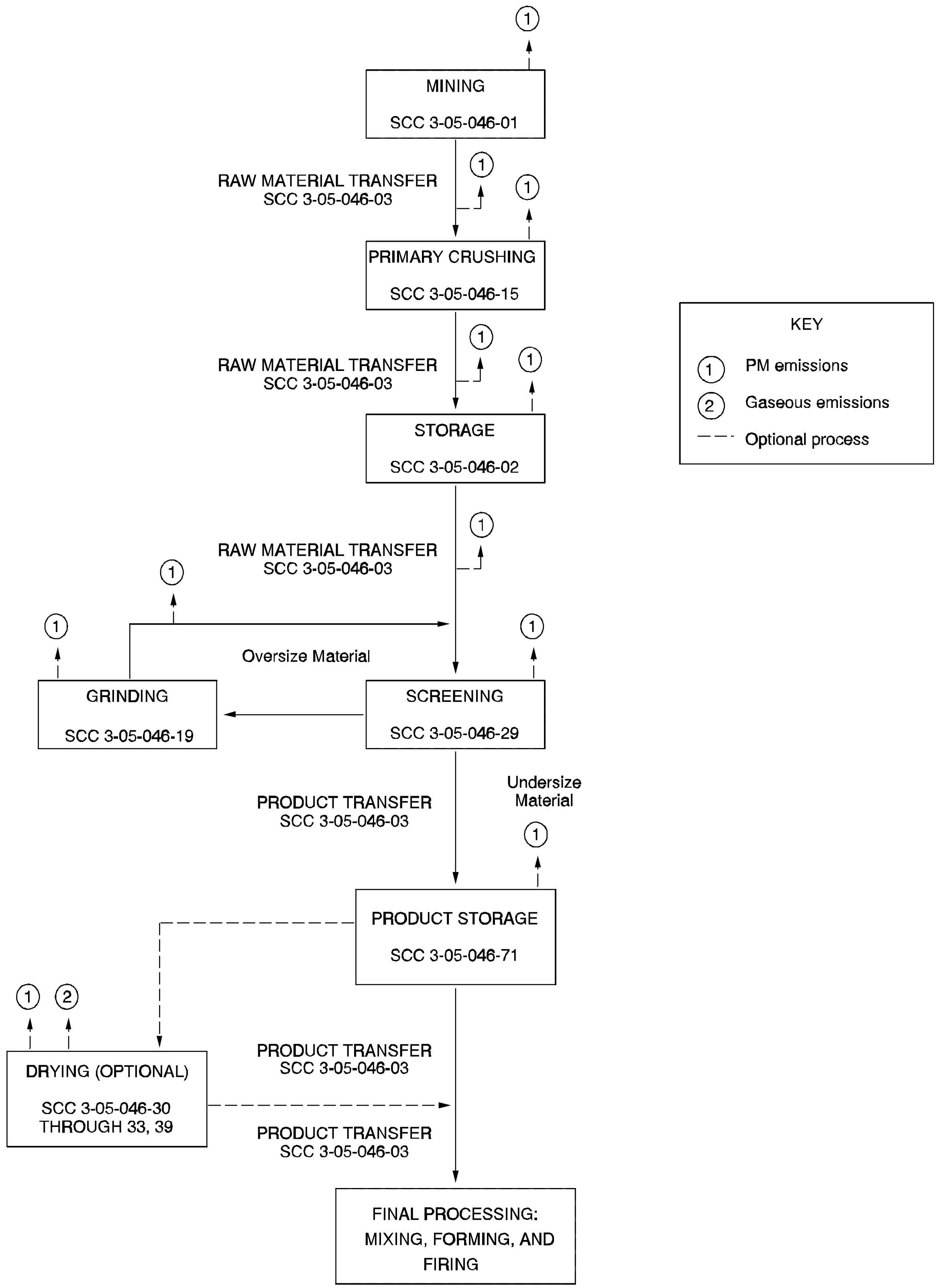

Figure 11.25-7. Process flow diagram for common clay and shale processing.
(SCC = Source Classification Code.)

Cyclones, wet scrubbers, and fabric filters are the most commonly used devices to control PM emissions from most clay processing operations. Cyclones often are used for product recovery from mechanical processes. In such cases, the cyclones are not considered to be an air pollution control device. Electrostatic precipitators also are used at some facilities to control PM emissions.

Tables 11.25-2 (metric units) and 11.25-3 (English units) present the emission factors for kaolin processing, and Table 11.25-4 presents particle size distributions for kaolin processing. Table 11.25-5 (metric and English units) presents the emission factors for ball clay processing. Emission factors for fire clay processing are presented in Tables 11.25-6 (metric units) and 11.25-7 (English units). Table 11.25-8 presents the particle size distributions for fire clay processing. Emission factors for bentonite processing are presented in Tables 11.25-9 (metric units) and 11.25-10 (English units), and Table 11.25-11 presents the particle size distribution for bentonite processing. Emission factors for processing common clay and shale to manufacture bricks are presented in AP-42 Section 11.3, "Bricks And Related Clay Products". No data are available for processing common clay and shale for other applications.

No data are available also for individual sources of emissions from fuller's earth processing operations. However, data from one fuller's earth plant indicate the following emission factors for combined sources controlled with multiclones and wet scrubbers: for fuller's earth dried from approximately 50 percent to approximately 12 percent, 0.69 kg/Mg (1.4 lb/ton) for filterable PM and 310 kg/Mg (610 lb/ton) for CO_2 emissions from a rotary dryer, rotary cooler, and packaging warehouse. For fuller's earth dried from approximately 12 percent to 1 to 2 percent, assume 0.32 kg/Mg (0.63 lb/ton) for filterable PM emissions from a rotary dryer, rotary cooler, grinding and screening operations, and packaging warehouse. It should be noted that the sources tested may not be representative of current fuller's earth processing operations.

Table 11.25-2 (Metric Units). EMISSION FACTORS FOR KAOLIN PROCESSING[a]

EMISSION FACTOR RATING: D

Source	Filterable PM[b]	Filterable PM-10[c]	CO_2
Spray dryer with fabric filter (SCC 3-05-041-31)	0.12[d]	ND	81[e]
Apron dryer (SCC 3-05-041-32)	0.62[f]	ND	140[f]
Multiple hearth furnace (SCC 3-05-041-40)	17[g]	8.2[g]	140[g]
Multiple hearth furnace with venturi scrubber (SCC 3-05-041-40)	0.12[g]	ND	NA
Flash calciner (SCC 3-05-041-42)	550[g]	280[g]	260[g]
Flash calciner with fabric filter (SCC 3-05-041-42)	0.028[g]	0.023[g]	NA

[a] Factors are kg/Mg produced. Emissions are uncontrolled, unless noted. SCC = Source Classification Code. ND = no data. NA = not applicable, control device has negligible effects on CO_2 emissions.
[b] Filterable PM is that PM collected on or before the filter of an EPA Method 5 (or equivalent) sampling train.
[c] Based on filterable PM emission factor and particle size data.
[d] References 3,5.
[e] Reference 5.
[f] Reference 6.
[g] Reference 8.

Table 11.25-3 (English Units). EMISSION FACTORS FOR KAOLIN PROCESSING[a]

EMISSION FACTOR RATING: D

Source	Filterable PM[b]	Filterable PM-10[c]	CO_2
Spray dryer with fabric filter (SCC 3-05-041-31)	0.23[d]	ND	160[e]
Apron dryer (SCC 3-05-041-32)	1.2[f]	ND	280[f]
Multiple hearth furnace (SCC 3-05-041-40)	34[g]	16[g]	280[g]
Multiple hearth furnace with venturi scrubber (SCC 3-05-041-40)	0.23[g]	ND	NA
Flash calciner (SCC 3-05-041-42)	1,100[g]	560[g]	510[g]
Flash calciner with fabric filter (SCC 3-05-041-42)	0.055[g]	0.046[g]	NA

[a] Factors are kg/Mg produced. Emissions are uncontrolled, unless noted. SCC = Source Classification Code. ND = no data. NA = not applicable, control device has negligible effects on CO_2 emissions.
[b] Filterable PM is that PM collected on or before the filter of an EPA Method 5 (or equivalent) sampling train.
[c] Based on filterable PM emission factor and particle size data.
[d] References 3,5.
[e] Reference 5.
[f] Reference 6.
[g] Reference 8.

Table 11.25-4. PARTICLE SIZE DISTRIBUTIONS FOR KAOLIN PROCESSING[a]

Particle Size, µm	Cumulative Percent Less Than Size		
	Multiple Hearth Furnace, Uncontrolled (SCC 3-05-041-40)	Flash Calciner (SCC 3-05-041-42)	
		Uncontrolled	With Fabric Filter
1.0	5.65	ND	26.93
1.25	8.21	11.14	31.88
2.5	22.99	25.32	55.29
6.0	42.1	44.65	77.34
10	47.22	50.87	88.31
15	52.02	55.35	94.77
20	56.61	59.45	96.56

[a] Reference 8. SCC = Source Classification Code. ND = no data.

Table 11.25-5 (Metric And English Units). EMISSION FACTORS FOR BALL CLAY PROCESSING[a]

EMISSION FACTOR RATING: D

Source	Filterable PM[b]	
	kg/Mg	lb/ton
Vibrating grate dryer with fabric filter (SCC 3-05-042-33)	0.071	0.14

[a] Reference 3. Factors are kg/Mg and lb/ton of ball clay processed. SCC = Source Classification Code.
[b] Filterable PM is that PM collected on or before the filter of an EPA Method 5 (or equivalent) sampling train.

Table 11.25-6 (Metric Units). EMISSION FACTORS FOR FIRE CLAY PROCESSING[a]

EMISSION FACTOR RATING: D

Process	SO_2	NO_x	CO_2	Filterable[b]	
				PM	PM-10
Rotary dryer[c] (SCC 3-05-043-30)	ND	ND	15[b]	33	8.1
Rotary dryer with cyclone[c] (SCC 3-05-043-30)	ND	ND	ND	5.6	2.6
Rotary dryer with cyclone and wet scrubber[c] (SCC 3-05-043-30)	ND	ND	ND	0.052	ND
Rotary calciner (SCC 3-05-043-40)	ND	ND	300[c]	62[d]	14[e]
Rotary calciner with multiclone (SCC 3-05-043-40)	ND	ND	ND	31[f]	ND
Rotary calciner with multiclone and wet scrubber (SCC 3-05-043-40)	3.8[d]	0.87[d]	ND	0.15[d]	0.031[e]

[a] Factors are kg/Mg of raw material feed. Emissions are uncontrolled, unless noted. SCC = Source Classification Code. ND = no data.
[b] Filterable PM is that PM collected on or before the filter of an EPA Method 5 (or equivalent) sampling train. PM-10 values are based on cascade impaction particle size distribution.
[c] Reference 11.
[d] References 12-13.
[e] Reference 12.
[f] Reference 13.

Table 11.25-7 (English Units). EMISSION FACTORS FOR FIRE CLAY PROCESSING[a]

EMISSION FACTOR RATING: D

Process	SO_2	NO_x	CO_2	Filterable[b]	
				PM	PM-10
Rotary dryer[c] (SCC 3-05-043-30)	ND	ND	30	65	16
Rotary dryer with cyclone[c] (SCC 3-05-043-30)	ND	ND	ND	11	5.1
Rotary dryer with cyclone and wet scrubber[c] (SCC 3-05-043-30)	ND	ND	ND	0.11	ND
Rotary calciner (SCC 3-05-043-40)	ND	ND	600[c]	120[d]	30[e]
Rotary calciner with multiclone (SCC 3-05-043-40)	ND	ND	ND	61[f]	ND
Rotary calciner with multiclone and wet scrubber (SCC 3-05-043-40)	7.6[d]	1.7[d]	ND	0.30[d]	0.062[e]

[a] Factors are kg/Mg of raw material feed. Emissions are uncontrolled, unless noted. SCC = Source Classification Code. ND = no data.

[b] Filterable PM is that PM collected on or before the filter of an EPA Method 5 (or equivalent) sampling train. PM-10 values are based on cascade impaction particle size distribution.

[c] Reference 11.

[d] References 12-13.

[e] Reference 12.

[f] Reference 13.

Table 11.25-8. PARTICLE SIZE DISTRIBUTIONS FOR FIRE CLAY PROCESSING[a]

EMISSION FACTOR RATING: D

Diameter (µm)	Uncontrolled	Multiclone Controlled	Cyclone Controlled	Cyclone/Scrubber Controlled
	Cumulative % Less Than Diameter	Cumulative % Less Than Diameter	Cumulative % Less Than Diameter	Cumulative % Less Than Diameter
Rotary Dryers (SCC 3-05-043-30)[b]				
2.5	2.5	ND	14	ND
6.0	10	ND	31	ND
10.0	24	ND	46	ND
15.0	37	ND	60	ND
20.0	51	ND	68	ND
Rotary Calciners (SCC 3-05-43-40)[c]				
1.0	3.1	13	ND	31
1.25	4.1	14	ND	43
2.5	6.9	23	ND	46
6.0	17	39	ND	55
10.0	34	50	ND	69
15.0	50	63	ND	81
20.0	62	81	ND	91

[a] For filterable PM only. SCC = Source Classification Code. ND = no data.
[b] Reference 11.
[c] References 12-13 (uncontrolled). Reference 12 (multiclone-controlled). Reference 13 (cyclone/scrubber-controlled).

Table 11.25-9 (Metric Units). EMISSION FACTORS FOR BENTONITE PROCESSING[a]

Source	Filterable PM[b]	EMISSION FACTOR RATING	PM-10[c]	EMISSION FACTOR RATING
Rotary dryer (SCC 3-05-044-30)	140	D	10	D
Rotary dryer with fabric filter (SCC 3-05-044-30)	0.050	D	0.037	D
Rotary dryer with ESP (SCC 3-05-044-30)	0.016	E	ND	

[a] Reference 3. Factors are kg/Mg produced. Emissions are uncontrolled, unless noted. SCC = Source Classification Code. ND = no data.
[b] Filterable PM is that PM collected on or before the filter of an EPA Method 5 (or equivalent) sampling train.
[c] Based on filterable PM emission factor and particle size data.

Table 11.25-10 (English Units). EMISSION FACTORS FOR BENTONITE PROCESSING[a]

Source	Filterable PM[b]	EMISSION FACTOR RATING	PM-10[c]	EMISSION FACTOR RATING
Rotary dryer (SCC 3-05-044-30)	290	D	20	D
Rotary dryer with fabric filter (SCC 3-05-044-30)	0.10	D	0.074	D
Rotary dryer with ESP (SCC 3-05-044-30)	0.033	E	ND	

[a] Reference 3. Factors are kg/Mg produced. Emissions are uncontrolled, unless noted. SCC = Source Classification Code. ND = no data.
[b] Filterable PM is that PM collected on or before the filter of an EPA Method 5 (or equivalent) sampling train.
[c] Based on filterable PM emission factor and particle size data.

Table 11.25-11. PARTICLE SIZE DISTRIBUTIONS FOR BENTONITE PROCESSING[a]

Particle Size, μm	Cumulative Percent Less Than Size	
	Rotary Dryer, Uncontrolled (SCC 3-05-044-30)	Rotary Dryer With Fabric Filter (SCC 3-05-044-30)
1.0	0.2	2.5
1.25	0.3	3.0
2.5	0.8	12
6.0	2.2	44
10.0	7.0	74
15.0	12	92
20.0	25	97

[a] Reference 3. SCC = Source Classification Code.

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