

Emission Factor Documentation for AP-42  
Section 11.5

Refractory Manufacturing

Final Report

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

EPA Contract 68-D2-0159  
Work Assignment No. I-01

MRI Project No. 4601-01

May 20, 1994

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

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## PREFACE

This report was prepared by Midwest Research Institute (MRI) for the Office of Air Quality Planning and Standards (OAQPS), U. S. Environmental Protection Agency (EPA), under Contract No. 68-D2-0159, Work Assignment No. I-01. Mr. Ron Myers was the requester of the work. The report was prepared by Richard Marinshaw and Brian Strong.

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EMISSION FACTOR DOCUMENTATION FOR AP-42 SECTION 11.5  
Refractory Manufacturing

1. INTRODUCTION

The document "Compilation of Air Pollutant Emissions 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 relates the quantity (weight) of pollutants emitted to a unit of activity of the source. The uses for the emission factors reported in AP-42 include:

1. Estimates of areawide emissions;
2. Estimates of emissions for a specific facility; and
3. Evaluation of emissions relative to ambient air quality.

The purpose of this report is to provide background information from test reports and other information to support revision of the AP-42 section on refractory manufacturing.

This background report consists of five sections. Section 1 includes the introduction to the report. Section 2 gives a description of the refractory manufacturing industry. It includes a characterization of the industry, an overview of the different process types, a description of emissions, and a description of the technology used to control emissions resulting from refractory manufacturing. Section 3 is a review of emissions data collection and analysis 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 revisions to the existing AP-42 section narrative and the development of pollutant emission factors. It includes the review of specific data sets and the results of data analysis. Section 5 presents AP-42 Section 11.5, Refractory Manufacturing.

## 2. INDUSTRY DESCRIPTION<sup>1</sup>

Refractories are materials that provide linings for high-temperature furnaces and other processing units. Refractories must be able to withstand physical wear, high temperatures (above 538EC [1000EF]), and corrosion by chemical agents. There are two general classifications of refractories: clay (Standard Industrial Classification [SIC] Code 3255) and nonclay (SIC Code 3297). The six-digit source classification code (SCC) for refractory manufacturing is 3-05-005.

Clay refractories are produced from fire clay (hydrous silicates of aluminum) and alumina (57 to 87.5 percent). Other clay minerals used in the production of refractories include kaolin, bentonite, ball clay, and common clay. Nonclay refractories are produced from a composition of alumina (<87.5 percent), mullite, chromite, magnesite, silica, silicon carbide, zircon, and other nonclays.

Refractories are produced in two basic forms: preshaped objects and unformed compositions in granulated or plastic forms. The preformed products are called bricks and shapes. These products are used to form the walls, arches, and floor tiles of various high-temperature process equipment. Unformed compositions include mortars, gunning mixes, castables (refractory concretes), ramming mixes, and plastics. These products are then cured to form a monolithic, internal structure after application.

### 2.1 CHARACTERIZATION OF THE INDUSTRY<sup>2</sup>

There are a total of approximately 280 refractory manufacturing plants operating in the United States. This total is divided more or less equally between clay and nonclay refractory plants. Refractory materials are produced in 37 States, and the leading producers are Ohio and Pennsylvania. Table 2-1

TABLE 2-1. LARGEST REFRACTORY MATERIALS PRODUCING STATES<sup>2</sup>

State	No. of refractory plants	
	Clay (SIC Code 3255)	Nonclay (SIC Code 3297)
Alabama	8	--
California	10	6
Georgia	5	4
Illinois	7	7
Indiana	--	7
Kentucky	--	6
Maryland	4	--
Michigan	--	7
Missouri	9	3
New York	--	3
New Jersey	--	7
North Carolina	--	2
Ohio	27	24
Pennsylvania	30	22
Texas	7	--
West Virginia	--	3

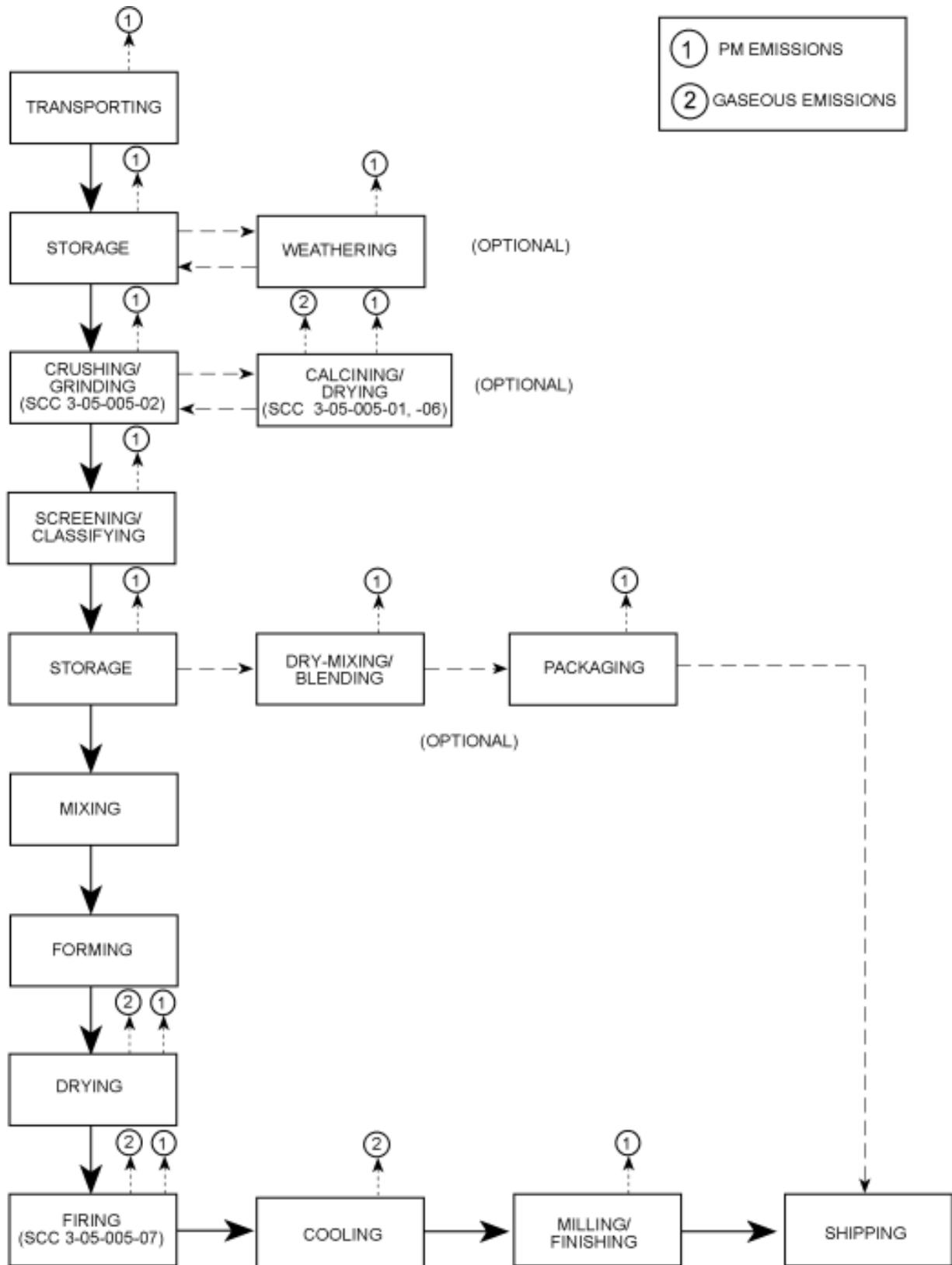


Figure 2-1. Refractory manufacturing process flow diagram.<sup>1</sup>

lists the number of plants by State for the largest producers of refractory materials. The largest producers of fire clay, which is the most widely used raw material for refractory manufacturing, are Missouri, Ohio, and Alabama. Total annual shipments of refractory materials in the United States is approximately \$2 billion.

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

Refractory manufacturing involves four processes: raw material processing, forming, firing, and final processing. Figure 2-1 illustrates the refractory manufacturing process. Raw material processing consists of crushing and grinding raw materials, followed by size classification and calcining and drying the raw materials, if necessary. Some of these processes are not required for certain types of refractory products. The processed raw material then may be dry-mixed with other minerals and chemical compounds, packaged, and shipped as product.

Forming consists of mixing the raw materials and forming them into the desired shapes. This process frequently occurs under wet or moist conditions. Firing involves heating the refractory material to high temperatures in a periodic (batch) or continuous tunnel kiln to form the ceramic bond that gives the product its refractory properties. The final processing stage involves milling, grinding, and sandblasting of the finished product. This step allows the product to maintain the correct shape and size after thermal expansion has occurred. For certain products, final processing may also include impregnating the product with tar and pitch, and final packaging.

Two other types of refractory processes also warrant discussion. The first is production of fused products. This process involves using an electric arc furnace to melt the refractory raw materials, then pouring the melted materials into sand molds for forming. Another type of refractory process is ceramic fiber production. In this process, calcined kaolin is melted in an electric arc furnace. The melted material is then fiberized in a blowchamber with a centrifuge device, or the molten clay is dropped into an air jet and is immediately blown into fine strands. After the blowchamber, the ceramic fiber may then be conveyed to an oven for curing, which adds structural rigidity to the fibers. During the curing process, oils are used to lubricate the fibers and the machinery used to handle and form the fibers. The production of ceramic fiber for refractory material is very similar to the production of mineral wool.

### 2.3 EMISSIONS<sup>3-8</sup>

The primary pollutant of concern that is emitted in refractory manufacturing is particulate matter (PM). Particulate matter emissions occur during the crushing, grinding, screening, calcining and drying of the raw materials, firing of the green refractory bricks, tar and pitch operations, and finishing of the refractories (grinding, milling, and sandblasting). The greatest emissions of PM are from the refractory firing kilns and electric arc furnaces.

Pollutants emitted as a result of combustion in the calcining and kilning processes include sulfur oxides (SO<sub>x</sub>), nitrogen oxides (NO<sub>x</sub>), carbon monoxide (CO), and volatile organic compounds (VOC's). Volatile organic compounds are also emitted by tar and pitch operations. The emission of SO<sub>x</sub> is a function of the sulfur content of certain clays and the plaster added to refractory materials to induce brick setting. Fluoride emissions occur during the kilning process and are a result of fluorides in the raw materials.

Chromium is used in several types of nonclay refractories, including chrome-magnesite (chromite-magnesite), magnesia-chrome, and chrome-alumina. Chromium compounds are emitted from the ore crushing and grinding, material drying and storage, and refractory firing and finishing processes used in producing these types of refractories. In addition, a number of elements in trace concentrations, including aluminum, beryllium, lead, mercury, manganese, nickel, titanium, vanadium, and zinc are emitted in trace amounts by drying, calcining, and firing operations of all types of refractory materials.

### 2.4 CONTROL TECHNOLOGY<sup>3-8</sup>

Emissions from crushing and grinding operations generally are controlled with fabric filters. Product recovery cyclones followed by wet scrubbers are used on calciners and dryers to control PM emissions from these sources.

Particulate matter emissions from kilns generally are not controlled. However, at least one refractory manufacturer currently uses a multiple-stage scrubber to control kiln emissions. Particulate matter emissions from electric arc furnaces generally are controlled with fabric filters. Particulate matter removal of 87 percent and fluoride removal of greater than 99 percent have been reported at one facility that uses an ionizing wet scrubber.

Volatile organic compounds emitted from tar and pitch operations generally are controlled by incineration, when inorganic particulates are not significant. Based on destruction of organic aerosols, a control efficiency in excess of 95 percent can be achieved using incinerators.

Emissions of PM from the ceramic fiber process also are controlled with fabric filters, and the efficiency is similar to that found in the fused cast refractory process. To control blowchamber emissions, a fabric filter is used to remove small pieces of fine threads that are formed in the fiberization stage. The efficiency of fabric filters in similar control devices exceeds 99 percent. Small particles of ceramic fiber are broken off or separated during the handling and forming of the fiber blankets in the curing oven. An oil is used in this process, and higher molecular weight organics are emitted. These emissions are controlled using a fabric filter followed by incineration. An overall efficiency in excess of 95 percent is expected for this type of control.

## REFERENCES FOR SECTION 2

1. *Refractories*, The Refractories Institute, Pittsburgh, PA, 1987.
2. *1987 Census of Manufactures*, U.S. Department of Commerce, Washington D.C., May 1990.
3. *Source Category Survey: Refractory Industry*, EPA-450/3-80-006, U. S. Environmental Protection Agency, Research Triangle Park, NC, March 1980.
4. *Locating and Estimating Air Emissions from Sources of Chromium*, EPA-450/4-84-007g, U. S. Environmental Protection Agency, Research Triangle Park, NC, 1985.
5. *Calciners and Dryers Emission Test Report, North American Refractories Company, Farber, Missouri*, EMB Report 84-CDR-14, U. S. Environmental Protection Agency, Research Triangle Park, NC, March 1984.
6. *Emission Test Report: Plant A*, Confidential Business Information Files, Document No. C-7-12, ESD Project No. 81/08, U. S. Environmental Protection Agency, Research Triangle Park, NC.
7. *Calciners and Dryers Emission Test Report, A. P. Green Company, Mexico, Missouri*, EMB Report 83-CDR-1, U. S. Environmental Protection Agency, Research Triangle Park, North Carolina, October 1983.
8. *Chromium Screening Study Test Report, Harbison-Walker Refractories, Baltimore, Maryland*, EMB Report 85-CHM-12, U. S. Environmental Protection Agency, Research Triangle Park, NC, June 1985.

### 3. GENERAL DATA REVIEW AND ANALYSIS

#### 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 Inventory Branch (EIB) were reviewed for information on the industry, processes, and emissions. The Crosswalk/Air Toxic Emission Factor Data Base Management System (XATEF) and the VOC/PM Speciation Data Base Management System (SPECIATE) 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 two data bases.

Information on the industry, including number of plants, plant location, and annual production capacities were obtained from the *Minerals Yearbook*, *Census of Minerals*, and *Census of Manufacturers*. 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 System (TSAR) data base was conducted to identify test reports for sources within the refractory manufacturing industry. Copies of these test reports were obtained from the files of the Emission Measurement Branch (EMB). The EPA library was searched for additional test reports. A list of plants that have been tested within the past 5 years was compiled from the AIRS data base. Using this information and information obtained on plant location from the *Minerals Yearbook*, *Census of Minerals*, and *Census of Manufacturers*, State and Regional offices were contacted about the availability of test reports. However, the information obtained from these offices was limited. Publications lists from the Office of Research and Development (ORD) and Control Technology Center (CTC) were also searched for reports on emissions from the refractory manufacturing industry. In addition, the Refractories Institute was contacted for assistance in obtaining information about the industry and emissions.

To reduce the amount of literature collected to a final group of references from which emission factors could be developed, the following general criteria were used:

1. Emissions 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 must contain test results based on more than one test run.
3. The report must contain sufficient data to evaluate the testing procedures and source operating conditions.

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 EMISSION 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 EIB 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 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 were 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 utilizing 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 always noted.

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

### REFERENCES 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 REVISIONS TO SECTION NARRATIVE

The revised AP-42 section described in this report replaces Section 8.5, Castable Refractories, in the previous version of AP-42. The existing section, which was last revised in 1972, addresses castable refractory manufacturing only and does not describe other types of refractory manufacturing processes and emissions. In addition, the quality of the data, upon which the existing section was based, is suspect. The draft section, which is based on more recent information, addresses several types of refractory manufacturing and provides a description of the industry and a process flow diagram.

### 4.2 POLLUTANT EMISSION FACTOR DEVELOPMENT

In addition to reviewing the data available in the background file for refractory manufacturing, a total of eight emission test reports were documented and reviewed in the process of revising the section on refractory manufacturing. Three of the tests (References 1, 2, and 3) were conducted as part of the emission test program for developing a new source performance standard (NSPS) for calciners and dryers in mineral processing industries. These tests were sponsored by EPA. Reference 4 documents a test conducted by EPA as part of the chromium screening study to identify significant sources of chromium emissions. The other four test reports reviewed were industry-sponsored compliance tests (References 5 through 8). All four of the industry-sponsored tests were rejected from consideration in developing emission factors. The emission test documented in Reference 5 was conducted at the same facility as the test documented in Reference 1. However, the data from Reference 5 was not considered for emission factor development because of anisokinetic conditions during testing. The emission test documented in Reference 6 was conducted at the same facility as the test documented in Reference 2. However, Reference 6 does not include process rate data and the test was conducted at sources other than those documented in Reference 2. References 7 and 8 lack adequate documentation of process rates for emission factor development. The four emission tests from which emission factors were developed are described below. Emission factors for refractory manufacturing included in the XATEF and SPECIATE data bases were also reviewed. A discussion of these emission factors is also presented. Finally, a discussion of the review of the existing test data in the AP-42 background file is presented.

#### 4.2.1 Review of Specific Data Sets

4.2.1.1 Reference 1. This test report included measurements of filterable PM, particle size distribution, and carbon dioxide (CO<sub>2</sub>) on a rotary dryer and was sponsored by EPA as part of the emission test program for the development of the proposed NSPS for calciners and dryers. Emission rates were measured for two types of fire clay used in refractory manufacturing--flint clay and plastic clay. A Method 5 sampling train was used for measuring the PM, and cascade impactors were used for quantifying the particle size distribution. The CO<sub>2</sub> emissions were measured using Method 3A (instrument analyzer).

Emissions from the dryer were controlled by means of a cyclone (for product recovery) followed by a wet scrubber in series. The wet scrubber operated with a pressure drop of 2.7 to 3.2 kilopascals (kPa) (11 to 13 inches of water [in. w.c.]). Three runs were conducted on each of the two clays. Uncontrolled emissions and controlled emissions, at both the cyclone and scrubber outlets, were measured. In addition, a trace element analysis of the PM catch was performed for each of the two

clays. Analysis of the plastic clay and flint clay samples identified aluminum, beryllium, calcium, chromium, iron, lead, mercury, magnesium, manganese, nickel, titanium, vanadium, and zinc.

A rating of A was assigned to both sets of PM, particle size distribution, and CO<sub>2</sub> data. The reports included adequate detail, the methodology appeared to be sound, and no problems were reported. The trace element data were not rated due to the fact that only one run was analyzed.

4.2.1.2 Reference 2. This test included measurements of filterable PM, particle size distribution, sulfur dioxide (SO<sub>2</sub>), and NO<sub>x</sub> on a coal-fired rotary calciner and was sponsored by EPA as part of the emission test program for the development of the proposed NSPS for calciners and dryers. A Method 5 sampling train was used for measuring the PM, and cascade impactors were used for quantifying the particle size distribution. Sulfur dioxide and NO<sub>x</sub> emissions were measured in accordance with EPA Reference Methods 6 and 7, respectively.

Emissions from the calciner were controlled by means of a multiclone (for product recovery) followed by a venturi scrubber in series. The scrubber operated at a pressure drop of 4.5 kPa (18 in. w.c.). Three runs were conducted. For PM and particle size distribution, uncontrolled emissions and controlled emissions at both the cyclone and scrubber outlets were measured. Sulfur dioxide and NO<sub>x</sub> emissions were measured at the scrubber outlet only. In addition, a trace element analysis of the PM catch for one run was performed. The analysis indicated trace amounts of aluminum, beryllium, calcium, chromium, iron, lead, mercury, magnesium, manganese, nickel, titanium, vanadium, and zinc.

A rating of A was assigned to the PM, particle size, SO<sub>2</sub>, and NO<sub>x</sub> test data. The reports included adequate detail, the methodology appeared to be sound, and no problems were reported. The trace element data were not rated due to the fact that only one run was analyzed.

4.2.1.3 Reference 3. This test included measurements of filterable PM and particle size distribution on a rotary calciner and was sponsored by EPA as part of the emission test program for the development of the proposed NSPS for calciners and dryers. A Method 5 sampling train was used for measuring the PM, and cascade impactors were used for quantifying the particle size distribution.

Emissions from the calciner were controlled by means of a multiclone (for product recovery) followed by a venturi scrubber in series. The scrubber operated at a pressure loss of 6 to 6.7 kPa (24 to 27 in. w.c.). A total of three runs were conducted. For PM and particle size distribution, uncontrolled emissions at the calciner outlet and controlled emissions at the scrubber outlet were measured. In addition, a trace element analysis of the PM catch was performed. The analysis identified calcium, chromium, iron, nickel, silicon, zinc, aluminum, magnesium, lead, mercury, and fluorine in the sample. However, because the run number for the trace element analysis was not identified in the report, it was not possible to develop emission factors from the data.

A rating of A was assigned to the PM and particle size test data. The reports included adequate detail. Although some changes were made in the number of sampling points and sampling time after the first run, the methodology appeared to be sound, and no problems were reported.

4.2.1.4 Reference 4. This test report documented measurements of filterable PM, hexavalent chromium (Cr<sup>+6</sup>), and total chromium emissions from a refractory rotary dryer and tunnel kiln. The particle size distributions of the dryer and kiln emissions also were measured. The plant uses magnesite

and chromite ores to manufacture chromite-magnesite refractory brick. The chromite content of the material processed varied from 14.5 to 46.3 percent. The test was sponsored by EPA as part of the screening study for industrial sources of chromium emissions.

A Method 5 sampling train (front half only) was used to measure filterable PM emissions. The Method 5 filter catch was analyzed for Cr<sup>+6</sup> using the diphenylcarbazide colorimetric method and for total chromium using neutron activation analysis. Particle size distribution was measured using cascade impactors with a preseparator.

Both uncontrolled and controlled (cyclone followed by a fabric filter) dryer PM emissions were sampled. However, because the controlled emissions included the dryer exhaust and the emissions from five material handling points, the emission factors developed from the controlled data are of limited use. Four test runs were conducted at both the cyclone inlet and fabric filter outlet. Three test runs of uncontrolled filterable PM emissions from a tunnel kiln also were conducted. In addition, four particle size distribution runs were conducted on the dryer exhaust and fabric filter outlet, and three particle size distribution runs were conducted on the kiln exhaust.

The PM and particle size distribution data are rated A. The data are presented in adequate detail and a sound methodology was used. The Cr<sup>+6</sup> and total chromium data are rated C due to the fact that the methods used were still under development at the time of the test.

#### 4.2.2 Review of XATEF and SPECIATE Data Base Emission Factors

The only emission factors for refractory manufacturing included in the XATEF data base are for chromium emissions from chromite-magnesite brick and chromic oxide brick production. The source of these emission factors traces back to a 1973 document (EPA-450/3-74-012), which references the 1972 version of AP-42. Because there is no further documentation of these emission factors in the AP-42 background files, the original source of these data could not be identified. Therefore, these emission factors do not satisfy the minimum criteria for inclusion in AP-42.

The SPECIATE data base includes a number of emission factors for refractory manufacturing. However, the emission factors are based on speciation profiles for average mineral products industry sources, and therefore do not satisfy the minimum criteria for inclusion in AP-42.

#### 4.2.3 Review of Test Data in AP-42 Background File

The previous version of AP-42 includes particulate emission factors for drying, crushing, electric arc melting, curing, and molding castable refractories. The emission factors are based on unpublished data from three stack tests that were conducted at a plant in Kentucky in 1967 and 1969. The background file contains estimates of annual emissions from the same facility for 1968 but does not contain any of the test data upon which the emission factors were based. Because of the lack of documentation and the fact that the tests predate the development of EPA reference methods, the test method and representativeness of the data are highly suspect. Therefore, the emission factors based on these data cannot be considered to be representative of the refractory manufacturing industry, so they were deleted from the section.

#### 4.2.4 Results of Data Analysis

Emission factors were developed for three types of refractory manufacturing sources: rotary dryers, rotary calciners, and tunnel kilns. The majority of these emission factors were developed for the processing of fire clay. However, emission factors also were developed for the processing of chromite-magnesite ore.

For rotary dryers, emission factors were developed for emissions of filterable PM, filterable PM-10, CO<sub>2</sub>, and several trace elements, including aluminum, beryllium, calcium, chromium, iron, lead, magnesium, manganese, mercury, nickel, titanium, vanadium, and zinc. These factors were developed from test data on two types of fire clay. In addition, rotary dryer emission factors for the drying of chromite-magnesite ore were developed for filterable PM, filterable PM-10, hexavalent chromium, and total chromium. Particle size distribution for emissions from the drying of both fire clay and chromite-magnesite ore also were developed from the data. For the drying of fire clay, Table 4-1 summarizes the test data on emissions of filterable PM, filterable PM-10, and CO<sub>2</sub>, and Table 4-2 summarizes the data on trace element emissions. Although separate data are presented in Table 4-1 for CO<sub>2</sub> emissions from uncontrolled and controlled rotary dryers, all the data are considered to be uncontrolled, because the control devices used (cyclones and scrubbers) achieve only incidental control of CO<sub>2</sub> emissions. For tunnel kilns, emission factors were developed for filterable PM, filterable PM-10, hexavalent chromium, and total chromium emissions from the firing of chromite-magnesite ore. Particle size distribution for emissions from the tunnel kilns firing chromite-magnesite ore also were developed from the data. Table 4-3 summarizes the test data on emissions of filterable PM, filterable PM-10, hexavalent chromium, and total chromium from the drying of chromite-magnesite ore. Table 4-4 summarizes the particle size distribution data for the drying of fire clay, and Table 4-5 summarizes the particle size distribution data for tunnel kiln emissions.

For rotary calciners, emission factors were developed for emissions of filterable PM, filterable PM-10, CO<sub>2</sub>, SO<sub>2</sub>, NO<sub>x</sub>, and several trace elements, including aluminum, beryllium, calcium, chromium, iron, lead, magnesium, manganese, mercury, nickel, titanium, vanadium, and zinc. These factors were developed from test data on the calcining of fire clay. Particle size distribution for emissions from calcining fire clay also was developed from the data. For calcining fire clay, Table 4-6 summarizes the test data on emissions of filterable PM, filterable PM-10, SO<sub>2</sub>, NO<sub>x</sub>, and CO<sub>2</sub>, and Table 4-7 summarizes the data on trace element emissions. Although separate data are presented in Table 4-6 for CO<sub>2</sub> emissions from uncontrolled and controlled rotary calciners, all the data is considered to be uncontrolled, because the control devices used (multiclones and scrubbers) achieve only incidental control of CO<sub>2</sub> emissions. Table 4-8 summarizes the particle size distribution data for the calcining of fire clay.

Although the emission factors discussed above for filterable PM, filterable PM-10, CO<sub>2</sub>, SO<sub>2</sub>, and NO<sub>x</sub>, are developed from A-rated test data, each of these factors is based on only one or two emission tests. Because of the relatively large number of refractory manufacturing plants (280), it is likely that the emission factors do not represent a random sample of the industry. For this reason, these emission factors are all assigned a quality rating of D. The emission factors developed for hexavalent chromium and total chromium emissions are developed from C-rated data. For this reason, these emission factors are rated E. Table 4-9 summarizes the emission factors developed for emissions of filterable PM, filterable PM-10, CO<sub>2</sub>, SO<sub>2</sub>, and NO<sub>x</sub> from the processing of fire clay; Table 4-10 summarizes the emission summarizes the emission factors developed for emissions of filterable PM, filterable PM-10, hexavalent chromium, and total chromium from the processing of chromite-magnesite ore. The emission

factors presented in Tables 4-4, 4-5, 4-8, 4-9, and 4-11 are incorporated into the revised AP-42 section on refractory manufacturing. Because the trace element emission factors are based on unrated data, these emission factors have not been incorporated into the revised AP-42 section. As discussed above, the refractory manufacturing emission factors in the previous version of AP-42 are highly suspect, and, therefore, have been deleted from the revised section.

TABLE 4-1. SUMMARY OF TEST DATA FOR REFRACTORY MANUFACTURING FOR CLAY ROTARY DRYERS<sup>a</sup>

Type of control	Pollutant	No. of test runs	Data rating	Emission factor		Type of clay
				Range, kg/Mg (lb/ton)	Average, kg/Mg (lb/ton)	
None	Filterable PM	3	A	17-53 (34-110)	32 (63)	Flint
None	Filterable PM	3	A	29-38 (58-77)	34 (67)	Plastic
Cyclone	Filterable PM	3	A	2.7-13 (5.4-25)	6.0 (12)	Flint
Cyclone	Filterable PM	3	A	2.8-6.9 (5.7-14)	5.1 (10)	Plastic
Cyclone/scrubber	Filterable PM	3	A	0.034-0.10 (0.067-0.21)	0.062 (0.12)	Flint
Cyclone/scrubber	Filterable PM	3	A	0.024-0.064 (0.048-0.13)	0.043 (0.085)	Plastic
None	CO <sub>2</sub>	3	A	11-18 (21-36)	13 (26)	Flint
None	CO <sub>2</sub>	3	A	7.1-13 (14-25)	9.7 (19)	Plastic
Cyclone	CO <sub>2</sub>	3	A	15-26 (30-52)	19 (37)	Flint
Cyclone	CO <sub>2</sub>	3	A	11-17 (22-34)	14 (28)	Plastic
Cyclone/scrubber	CO <sub>2</sub>	3	A	13-33 (26-67)	20 (40)	Flint
Cyclone/scrubber	CO <sub>2</sub>	3	A	12-17 (23-35)	14 (29)	Plastic

<sup>a</sup>Reference 1. Emission factors in units kilograms of pollutant emitted per megagram of material processed (kg/Mg) (pounds of pollutant emitted per ton of material processed [lb/ton]).

TABLE 4-2. SUMMARY OF TRACE ELEMENT EMISSION DATA FOR  
CLAY ROTARY DRYERS<sup>a</sup>

Flint clay

Pollutant	Uncontrolled		Cyclone		Cyclone/scrubber	
	Emission factor		Emission factor		Emission factor	
	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton
Aluminum	1.1	2.2	0.14	0.27	0.0044	0.0088
Beryllium	1.2x10 <sup>-5</sup>	2.3x10 <sup>-5</sup>	b	b	b	b
Calcium	0.011	0.022	0.0018	0.0036	0.00070	0.0014
Chromium	0.0031	0.0063	0.00023	0.00046	1.4x10 <sup>-5</sup>	2.9x10 <sup>-5</sup>
Iron	0.12	0.24	0.018	0.037	0.00068	0.0014
Lead	0.00056	0.0011	0.00010	0.00020	7.4x10 <sup>-6</sup>	1.5x10 <sup>-5</sup>
Magnesium	0.020	0.040	0.0024	0.0048	0.00016	0.00033
Manganese	0.00087	0.0017	b	b	5.2x10 <sup>-6</sup>	1.0x10 <sup>-5</sup>
Mercury	6.0x10 <sup>-6</sup>	1.2x10 <sup>-5</sup>	2.2x10 <sup>-6</sup>	4.4x10 <sup>-6</sup>	6.5x10 <sup>-7</sup>	1.3x10 <sup>-6</sup>
Nickel	0.0063	0.013	0.00013	0.00027	9.1x10 <sup>-6</sup>	1.8x10 <sup>-5</sup>
Titanium	0.0015	0.0030	0.00044	0.00088	0.00011	0.00021
Vanadium	0.0011	0.0023	0.00017	0.00034	9.1x10 <sup>-6</sup>	1.8x10 <sup>-5</sup>
Zinc	0.0058	0.012	0.00012	0.00025	2.5x10 <sup>-5</sup>	4.9x10 <sup>-5</sup>

Plastic clay

Pollutant	Uncontrolled		Cyclone		Cyclone/scrubber	
	Emission factor		Emission factor		Emission factor	
	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton
Aluminum	2.4	4.7	0.40	0.79	0.0037	0.0075
Beryllium	8.2x10 <sup>-5</sup>	0.00016	1.1x10 <sup>-5</sup>	2.2x10 <sup>-5</sup>	b	b
Calcium	0.072	0.14	0.011	0.023	0.0014	0.0028
Chromium	0.0055	0.011	0.00098	0.0020	9.7x10 <sup>-6</sup>	1.9x10 <sup>-5</sup>
Iron	0.19	0.39	0.029	0.058	0.00039	0.00078
Lead	0.00092	0.0018	0.00015	0.00031	5.8x10 <sup>-6</sup>	1.2x10 <sup>-5</sup>
Magnesium	0.0084	0.017	0.0077	0.015	0.00045	0.00090
Manganese	b	b	b	b	3.2x10 <sup>-6</sup>	6.4x10 <sup>-6</sup>
Mercury	2.0x10 <sup>-5</sup>	4.0x10 <sup>-5</sup>	4.5x10 <sup>-6</sup>	9.0x10 <sup>-6</sup>	6.4x10 <sup>-7</sup>	1.3x10 <sup>-6</sup>
Nickel	0.0029	0.0057	0.00073	0.0015	1.1x10 <sup>-5</sup>	2.3x10 <sup>-5</sup>
Titanium	0.0025	0.0051	0.00060	0.0012	5.9x10 <sup>-5</sup>	0.00012
Vanadium	0.0036	0.0073	0.00063	0.0013	5.6x10 <sup>-6</sup>	1.1x10 <sup>-5</sup>
Zinc	0.0021	0.0042	0.00026	0.00052	3.0x10 <sup>-5</sup>	6.1x10 <sup>-5</sup>

TABLE 4-2 (continued)

Average of results of plastic and flint clays

Pollutant	Uncontrolled		Cyclone		Cyclone/scrubber	
	Emission factor		Emission factor		Emission factor	
	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton
Aluminum	1.7	3.5	0.27	0.53	0.0041	0.0081
Beryllium	$4.7 \times 10^{-5}$	$9.3 \times 10^{-5}$	$1.1 \times 10^{-5}$	$2.2 \times 10^{-5}$	b	b
Calcium	0.041	0.083	0.0066	0.013	0.0011	0.0021
Chromium	0.0043	0.0087	0.00061	0.0012	$1.2 \times 10^{-5}$	$2.4 \times 10^{-5}$
Iron	0.16	0.32	0.024	0.047	0.00053	0.0011
Lead	0.00074	0.0015	0.00013	0.00025	$6.6 \times 10^{-6}$	$1.3 \times 10^{-5}$
Magnesium	0.014	0.028	0.0051	0.010	0.00031	0.00061
Manganese	0.00087	0.0017	b	b	$4.2 \times 10^{-6}$	$8.2 \times 10^{-6}$
Mercury	$1.3 \times 10^{-5}$	$2.6 \times 10^{-5}$	$3.4 \times 10^{-6}$	$6.7 \times 10^{-6}$	$6.5 \times 10^{-7}$	$1.3 \times 10^{-6}$
Nickel	0.0046	0.0092	0.00043	0.00087	$1.0 \times 10^{-5}$	$2.0 \times 10^{-5}$
Titanium	0.0020	0.0040	0.00052	0.0010	$8.3 \times 10^{-5}$	0.00017
Vanadium	0.0024	0.0048	0.00040	0.00080	$7.4 \times 10^{-6}$	$1.5 \times 10^{-5}$
Zinc	0.0039	0.0079	0.00019	0.00038	$2.8 \times 10^{-5}$	$5.5 \times 10^{-5}$

<sup>a</sup>Based on 1 run; data are not rated. Emission factors in units kilograms of pollutant emitted for megagram of material processed (kg/Mg) (pounds of pollutant emitted per ton of material processed [lb/ton]).

<sup>b</sup>Below detection limit.

TABLE 4-3. SUMMARY OF TEST DATA FOR REFRACTORY MANUFACTURING FOR CHROMITE/MAGNESITE ORE ROTARY DRYERS AND TUNNEL KILNS

Process	Type of control	Pollutant	No. of test runs	Data rating	Emission factor		Ref. No.
					Range, kg/Mg Cr <sub>2</sub> O <sub>3</sub> (lb/ton Cr <sub>2</sub> O <sub>3</sub> )	Average, kg/Mg Cr <sub>2</sub> O <sub>3</sub> (lb/ton Cr <sub>2</sub> O <sub>3</sub> )	
Rotary dryer	None	Filterable PM	4	A	0.45 to 1.4 (0.90 to 2.7)	0.83 1.7	4
	Cyclone/fabric filter	Filterable PM	4	A	0.11 to 0.21 (0.22 to 0.43)	0.15 0.30	4
	None	Hexavalent chromium	4	C	1.3x10 <sup>-6</sup> to 4.2x10 <sup>-6</sup> (2.6x10 <sup>-6</sup> to 8.3x10 <sup>-6</sup> )	2.5x10 <sup>-6</sup> (5.0x10 <sup>-6</sup> )	4
	Cyclone/fabric filter	Hexavalent chromium	4	C	9.9x10 <sup>-7</sup> to 2.6x10 <sup>-6</sup> (2.0x10 <sup>-6</sup> to 5.3x10 <sup>-6</sup> )	1.6x10 <sup>-6</sup> (3.2x10 <sup>-6</sup> )	4
	None	Total chromium	4	C	0.0094 to 0.077 (0.019 to 0.15)	0.037 (0.073)	4
	Cyclone/fabric filter	Total chromium	4	C	0.0018 to 0.012 (0.0035 to 0.024)	0.0062 (0.012)	4
Tunnel kiln	None	Filterable PM	3	A	0.26 to 0.55 (0.51 to 1.1)	0.41 (0.82)	4
	None	Hexavalent chromium	3	A	0.00013 to 0.00016 (0.00025 to 0.00031)	0.00015 (0.00029)	4
	None	Total chromium	3	A	0.0017 to 0.0031 (0.0033 to 0.0062)	0.0023 (0.0046)	4

TABLE 4-4. SUMMARY OF PARTICLE SIZE DATA FOR CLAY ROTARY DRYERS

Flint clay

Diameter, micrometers	Uncontrolled			Controlled (cyclone)		
	Cumulative % less than diameter	Emission factor <sup>b</sup>		Cumulative % less than diameter	Emission factor <sup>c</sup>	
		kg/Mg	lb/ton		kg/Mg	lb/ton
2.5	3	1.0	1.9	13	0.78	1.6
6.0	14	4.5	8.8	32	1.9	3.8
10.0	36	12	23	53	3.2	6.4
15.0	50	16	32	71	4.3	8.5
20.0	66	21	42	78	4.7	9.4

Plastic clay

Diameter, micrometers	Uncontrolled			Controlled (cyclone)		
	Cumulative % less than diameter	Emission factor <sup>d</sup>		Cumulative % less than diameter	Emission factor <sup>e</sup>	
		kg/Mg	lb/ton		kg/Mg	lb/ton
2.5	2	0.68	1.3	14	0.71	1.4
6.0	6	2.0	4.0	29	1.5	2.9
10.0	12	4.1	8.0	38	1.9	3.8
15.0	24	8.2	16	48	2.4	4.8
20.0	36	12	24	57	2.9	5.7

Average

Diameter, micrometers	Uncontrolled			Controlled (cyclone)		
	Cumulative % less than diameter	Emission factor		Cumulative % less than diameter	Emission factor	
		kg/Mg	lb/ton		kg/Mg	lb/ton
2.5	3	0.84	1.6	14%	0.75	1.5
6.0	10	3.3	6.4	31%	1.7	3.4
10.0	24	8.1	16	46%	2.6	5.1
15.0	37	12	24	60%	3.4	6.7
20.0	51	17	33	68%	3.8	7.6

<sup>a</sup>Reference 1.

<sup>b</sup>Based on average uncontrolled filterable PM emission factor of 32 kg/Mg (63 lb/ton).

<sup>c</sup>Based on average cyclone-controlled filterable PM emission factor of 6.0 kg/Mg (12 lb/ton).

<sup>d</sup>Based on average uncontrolled filterable PM emission factor of 34 kg/Mg (67 lb/ton).

<sup>e</sup>Based on average cyclone-controlled filterable PM emission factor of 5.1 kg/Mg (10 lb/ton).

**TABLE 4-5. SUMMARY OF PARTICLE SIZE DATA  
FOR CHROMITE-MAGNESITE ORE:  
ROTARY DRYERS AND TUNNEL KILNS<sup>a</sup>**

Uncontrolled rotary dryer

Diameter, micro- meters	Filterable PM			Hexavalent chromium			Total chromium		
	Cumulative % less than dia- meter	Emission factor <sup>b</sup>		Cumulative % less than dia- meter	Emission factor <sup>c</sup>		Cumulative % less than dia- meter	Emission factor <sup>d</sup>	
		kg/Mg	lb/ton		kg/Mg	lb/ton		kg/Mg	lb/ton
1	1.2	0.010	0.020	3.5	8.8x10 <sup>-8</sup>	1.8x10 <sup>-7</sup>	0.8	0.0030	0.00058
5	13	0.11	0.22	39	9.8x10 <sup>-7</sup>	2.0x10 <sup>-6</sup>	9	0.0033	0.0066
10	24	0.20	0.41	64	1.6x10 <sup>-6</sup>	3.2x10 <sup>-6</sup>	19	0.0070	0.014

Uncontrolled tunnel kiln

Diameter, micro- meters	Filterable PM			Hexavalent chromium			Total chromium		
	Cumulative % less than dia- meter	Emission factor <sup>e</sup>		Cumulative % less than dia- meter	Emission factor <sup>f</sup>		Cumulative % less than dia- meter	Emission factor <sup>g</sup>	
		kg/Mg	lb/ton		kg/Mg	lb/ton		kg/Mg	lb/ton
1	71	0.29	0.58	71	0.00011	0.00021	84	0.0019	0.0039
5	78	0.32	0.64	81	0.00012	0.00023	91	0.0021	0.0042
10	84	0.34	0.69	84	0.00013	0.00025	93	0.0021	0.0043

<sup>a</sup>Reference 4.

<sup>b</sup>Based on average uncontrolled filterable PM emission factor of 0.83 kg/Mg (1.7 lb/ton).

<sup>c</sup>Based on average uncontrolled hexavalent chromium emission factor of 2.5x10<sup>-6</sup> kg/Mg (5.0x10<sup>-6</sup> lb/ton).

<sup>d</sup>Based on average uncontrolled total chromium emission factor of 0.037 kg/Mg (0.073 lb/ton).

<sup>e</sup>Based on average uncontrolled filterable PM emission factor of 0.41 kg/Mg (0.82 lb/ton).

<sup>f</sup>Based on average uncontrolled hexavalent chromium emission factor of 0.00015 kg/Mg (0.00029 lb/ton).

<sup>g</sup>Based on average uncontrolled total chromium emission factor of 0.0023 kg/Mg (0.0046 lb/ton).

TABLE 4-6. SUMMARY OF TEST DATA FOR REFRACTORY MANUFACTURING:  
CLAY ROTARY CALCINERS

Type of control	Pollutant	No. of test runs	Data rating	Emission factor		Ref. No.
				Range, kg/Mg (lb/ton)	Average, kg/Mg (lb/ton)	
None	Filterable PM	3	A	60-73 (120-145)	66 (130)	2
None	Filterable PM	3	A	49-65 (99-130)	57 (110)	3
Multiclone	Filterable PM	3	A	30-32 (60-63)	31 (61)	2
Multiclone/ scrubber	Filterable PM	3	A	0.25-0.27 (0.49-0.54)	0.26 (0.51)	2
Multiclone/ scrubber	Filterable M	3	A	0.032-0.070 (0.064-0.14)	0.045 (0.090)	3
None	CO <sub>2</sub>	3	A	360-410 (710-810)	380 (760)	2
None	CO <sub>2</sub>	3	A	290-310 (570-620)	300 (600)	3
Multiclone	CO <sub>2</sub>	3	A	330-360 (660-720)	340 (680)	2
Multiclone/ scrubber	CO <sub>2</sub>	3	A	270-280 (530-560)	270 (550)	2
Multiclone/ scrubber	CO <sub>2</sub>	3	A	210-230 (420-460)	220 (440)	3
Multiclone/ scrubber	SO <sub>2</sub>	3	A	3.7-3.9 (7.4-7.8)	3.8 (7.6)	2
Multiclone/ scrubber	NO <sub>x</sub>	3	A	0.75-0.96 (1.5-1.9)	0.87 (1.7)	2

TABLE 4-7. SUMMARY OF TRACE ELEMENT DATA FOR CLAY ROTARY CALCINERS<sup>a</sup>

Pollutant	Uncontrolled		Multiclone		Multiclone/scrubber	
	Emission factor		Emission factor		Emission factor	
	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton
Aluminum	3.4	6.9	1.2	2.4	0.011	0.021
Beryllium	8.0x10 <sup>-5</sup>	0.00016	8.0x10 <sup>-5</sup>	0.00016	b	b
Calcium	0.080	0.16	0.055	0.11	0.0027	0.0054
Chromium	0.0070	0.014	0.0018	0.0037	2.6x10 <sup>-5</sup>	5.2x10 <sup>-5</sup>
Iron	0.31	0.62	0.19	0.37	0.0011	0.0023
Lead	0.0019	0.0038	0.0012	0.0025	3.6x10 <sup>-5</sup>	7.1x10 <sup>-5</sup>
Magnesium	0.024	0.049	0.021	0.041	0.00028	0.00057
Manganese	0.00072	0.0014	0.00032	0.00064	b	b
Mercury	0.00014	0.00028	5.1x10 <sup>-5</sup>	0.00010	3.9x10 <sup>-6</sup>	7.8x10 <sup>-6</sup>
Nickel	0.0049	0.0098	0.0018	0.0036	3.6x10 <sup>-5</sup>	7.2x10 <sup>-5</sup>
Titanium	0.041	0.081	0.025	0.050	0.00035	0.00070
Vanadium	0.0049	0.0099	0.0032	0.0065	7.2x10 <sup>-5</sup>	0.00014
Zinc	0.020	0.039	0.0017	0.0034	8.7x10 <sup>-5</sup>	0.00017

<sup>a</sup>Reference 2; based on 1 run; data are not rated.

<sup>b</sup>Below detection limit.

TABLE 4-8. SUMMARY OF PARTICLE SIZE DATA FOR CLAY ROTARY CALCINERS

Reference 2

Diameter, micro- meters	Uncontrolled		
	Cumulative % less than diameter	Emission factor <sup>a</sup>	
		kg/Mg	lb/ton
1.0	5.5	3.6	7.2
1.25	7	4.6	9.1
2.5	11	7.2	14
6.0	23	15	30
10.0	43	28	56
15.0	62	40	81
20.0	72	47	94

Diameter, micro- meters	Controlled (multiclone)		
	Cumulative % less than diameter	Emission factor <sup>b</sup>	
		kg/Mg	lb/ton
1.0	13	3.8	7.6
1.25	14	4.3	8.7
2.5	23	6.9	14
6.0	39	12	24
10.0	50	15	30
15.0	63	19	38
20.0	81	25	49

Reference 3

Diameter (microns)	Uncontrolled			Controlled (multiclone/scrubber)		
	Cumulative % less than diameter	Emission factor <sup>c</sup>		Cumulative % less than diameter	Emission factor <sup>d</sup>	
		kg/Mg	lb/ton		kg/Mg	lb/ton
1.0	0.76	0.43	0.86	31	0.014	0.028
1.25	1.1	0.63	1.2	43	0.019	0.039
2.5	2.7	1.5	3.0	46	0.021	0.041
6.0	11	6.3	12	55	0.025	0.050
10.0	25	14	28	69	0.031	0.062
15.0	38	22	43	81	0.036	0.073
20.0	52	30	57	91	0.041	0.082

TABLE 4-8. (continued)

Average of Reference 2 and 3 data

Diameter, micrometers	Uncontrolled		
	Cumulative % less than diameter	Emission factor	
		kg/Mg	lb/ton
1.0	3.1	1.9	3.8
1.25	4.1	2.4	4.9
2.5	6.9	4.1	8.2
6.0	17	10	20
10.0	34	20	41
15.0	50	30	60
20.0	62	37	74

<sup>a</sup>Based on average uncontrolled filterable PM emission factor of 65 kg/Mg (130 lb/ton).

<sup>b</sup>Based on average multiclone-controlled filterable PM emission factor of 31 kg/Mg (61 lb/ton).

<sup>c</sup>Based on average uncontrolled filterable PM emission factor of 57 kg/Mg (110 lb/ton).

<sup>d</sup>Based on average multiclone/scrubber-controlled filterable PM emission factor of 0.045 kg/Mg (0.090 lb/ton).

TABLE 4-9. SUMMARY OF CRITERIA POLLUTANT EMISSION FACTORS DEVELOPED FOR REFRACTORY MANUFACTURING: CLAY ORE

Process	Type of control	Pollutant	No. of tests	Average emission factor, kg/Mg (lb/ton)	Emission factor rating	References
Rotary dryer	None	Filterable PM	2	33 (65)	D	1
Rotary dryer	Cyclone	Filterable PM	2	5.6 (11)	D	1
Rotary dryer	Cyclone/scrubber	Filterable PM	2	0.052 (0.11)	D	1
Rotary dryer	None	Filterable PM-10	2	8.1 (16)	D	1
Rotary dryer	Cyclone	Filterable PM-10	2	2.6 (5.1)	D	1
Rotary dryer	None	CO <sub>2</sub>	6	15 (30)	D	1
Rotary calciner	None	Filterable PM	2	62 (120)	D	2, 3
Rotary calciner	Multiclone	Filterable PM	1	31 (61)	D	2
Rotary calciner	Multiclone/scrubber	Filterable PM	2	0.15 (0.30)	D	2, 3
Rotary calciner	None	Filterable PM-10	2	20 (41)	D	2, 3
Rotary calciner	Multiclone	Filterable PM-10	1	15 (30)	D	2
Rotary calciner	Multiclone/scrubber	Filterable PM-10	1	0.031 (0.062)	D	3
Rotary calciner	None	CO <sub>2</sub>	5	300 (600)	D	2, 3
Rotary calciner	Multiclone/scrubber	SO <sub>2</sub>	1	3.8 (7.6)	D	2
Rotary calciner	Multiclone/scrubber	NO <sub>x</sub>	1	0.87 (1.7)	D	2

TABLE 4-10. SUMMARY OF TRACE ELEMENTS EMISSION FACTORS DEVELOPED FOR REFRACTORY MANUFACTURING: CLAY ORE

Process	Type of control	Pollutant	No. of Tests	Average emission factor		References
				kg/Mg	lb/ton	
Rotary dryer	None	Aluminum	2	1.7	3.5	1
		Beryllium	2	4.7x10 <sup>-5</sup>	9.3x10 <sup>-5</sup>	1
		Calcium	2	0.041	0.083	1
		Chromium	2	0.0043	0.0087	1
		Iron	2	0.16	0.32	1
		Lead	2	0.00074	0.0015	1
		Magnesium	2	0.014	0.028	1
		Manganese	2	0.00087	0.0017	1
		Mercury	2	1.3x10 <sup>-5</sup>	2.6x10 <sup>-5</sup>	1
		Nickel	2	0.0046	0.0092	1
		Titanium	2	0.0020	0.0040	1
		Vanadium	2	0.0024	0.0048	1
		Zinc	2	0.0039	0.0079	1
	Cyclone	Aluminum	2	0.27	0.53	1
		Beryllium	2	1.1x10 <sup>-5</sup>	2.2x10 <sup>-5</sup>	1
		Calcium	2	0.0066	0.013	1
		Chromium	2	0.00061	0.0012	1
		Iron	2	0.024	0.047	1
		Lead	2	0.00013	0.00025	1
		Magnesium	2	0.0051	0.010	1
		Mercury	2	3.4x10 <sup>-6</sup>	6.7x10 <sup>-6</sup>	1
		Nickel	2	0.00043	0.00087	1
Titanium	2	0.00052	0.0010	1		
Vanadium	2	0.00040	0.00080	1		
Zinc	2	0.00019	0.00038	1		

TABLE 4-10. (continued)

Process	Type of control	Pollutant	No. of Tests	Average emission factor		References
				kg/Mg	lb/ton	
Rotary dryer (continued)	Cyclone/ scrubber	Aluminum	2	0.0041	0.0081	1
		Calcium	2	0.0011	0.0021	1
		Chromium	2	1.2x10 <sup>-5</sup>	2.4x10 <sup>-5</sup>	1
		Iron	2	0.00053	0.0011	1
		Lead	2	6.6x10 <sup>-6</sup>	1.3x10 <sup>-5</sup>	1
		Magnesium	2	0.00031	0.00061	1
		Manganese	2	4.2x10 <sup>-6</sup>	8.2x10 <sup>-6</sup>	1
		Mercury	2	6.5x10 <sup>-7</sup>	1.3x10 <sup>-6</sup>	1
		Nickel	2	1.0x10 <sup>-5</sup>	2.0x10 <sup>-5</sup>	1
		Titanium	2	8.3x10 <sup>-5</sup>	0.00017	1
		Vanadium	2	7.4x10 <sup>-6</sup>	1.5x10 <sup>-5</sup>	1
		Zinc	2	2.8x10 <sup>-5</sup>	5.5x10 <sup>-5</sup>	1
Rotary calciner	None	Aluminum	1	3.4	6.9	2
		Beryllium	1	8.0x10 <sup>-5</sup>	0.00016	2
		Calcium	1	0.080	0.16	2
		Chromium	1	0.0070	0.014	2
		Iron	1	0.31	0.62	2
		Lead	1	0.0019	0.0038	2
		Magnesium	1	0.024	0.049	2
		Manganese	1	0.00072	0.0014	2
		Mercury	1	0.00014	0.00028	2
		Nickel	1	0.0049	0.0098	2
		Titanium	1	0.041	0.081	2
		Vanadium	1	0.0049	0.0099	2
		Zinc	1	0.020	0.039	2

TABLE 4-10. (continued)

Process	Type of control	Pollutant	No. of Tests	Average emission factor		References
				kg/Mg	lb/ton	
Rotary calciner (continued)	Multiclone	Aluminum	1	1.2	2.4	2
		Beryllium	1	8.0x10 <sup>-5</sup>	0.00016	2
		Calcium	1	0.055	0.11	2
		Chromium	1	0.0018	0.0037	2
		Iron	1	0.19	0.37	2
		Lead	1	0.0012	0.0025	2
		Magnesium	1	0.021	0.041	2
		Manganese	1	0.00032	0.00064	2
		Mercury	1	5.1x10 <sup>-5</sup>	0.00010	2
		Nickel	1	0.0018	0.0036	2
		Titanium	1	0.025	0.050	2
		Vanadium	1	0.0032	0.0065	2
		Zinc	1	0.0017	0.0034	2
	Multiclone/ scrubber	Aluminum	1	0.011	0.021	2
		Calcium	1	0.0027	0.0054	2
		Chromium	1	2.6x10 <sup>-5</sup>	5.2x10 <sup>-5</sup>	2
		Iron	1	0.0011	0.0023	2
		Lead	1	3.6x10 <sup>-5</sup>	7.1x10 <sup>-5</sup>	2
		Magnesium	1	0.00028	0.00057	2
		Mercury	1	3.9x10 <sup>-6</sup>	7.8x10 <sup>-6</sup>	2
		Nickel	1	3.6x10 <sup>-5</sup>	7.2x10 <sup>-5</sup>	2
		Titanium	1	0.00035	0.00070	2
Vanadium	1	7.2x10 <sup>-5</sup>	0.00014	2		
Zinc	1	8.7x10 <sup>-5</sup>	0.00017	2		

<sup>a</sup>Emission factors are not rated.

TABLE 4-11. SUMMARY OF EMISSION FACTORS DEVELOPED FOR REFRACTORY MANUFACTURING: CHROMITE/MAGNESITE ORE

Process	Type of control	Pollutant	No. of tests	Average emission factor, kg/Mg Cr <sub>2</sub> O <sub>3</sub> (lb/ton Cr <sub>2</sub> O <sub>3</sub> )	Emission factor rating	Ref. No.
Rotary dryer	None	Filterable PM	1	0.83 (1.7)	D	4
		Filterable PM-10	1	0.20 (0.41)	D	4
		Hexavalent chromium	1	2.5x10 <sup>-6</sup> (5.0x10 <sup>-6</sup> )	E	4
		Total chromium	1	0.037 (0.073)	E	4
	Cyclone/ fabric filter	Filterable PM	1	0.15 (0.30)	D	4
		Hexavalent chromium	1	1.6x10 <sup>-6</sup> (3.2x10 <sup>-6</sup> )	E	4
		Total chromium	1	0.0062 (0.012)	E	4
Tunnel kiln	None	Filterable PM	1	0.41 (0.82)	D	4
		Filterable PM-10	1	0.34 (0.69)	D	4
		Hexavalent chromium	1	0.00015 (0.00029)	E	4
		Total chromium	1	0.0023 (0.0046)	E	4

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## 5. PROPOSED AP-42 SECTION 11.5

A proposed revision of the existing AP-42 Section 8.5, Castable Refractories, is presented in the following pages as it would appear in the document.

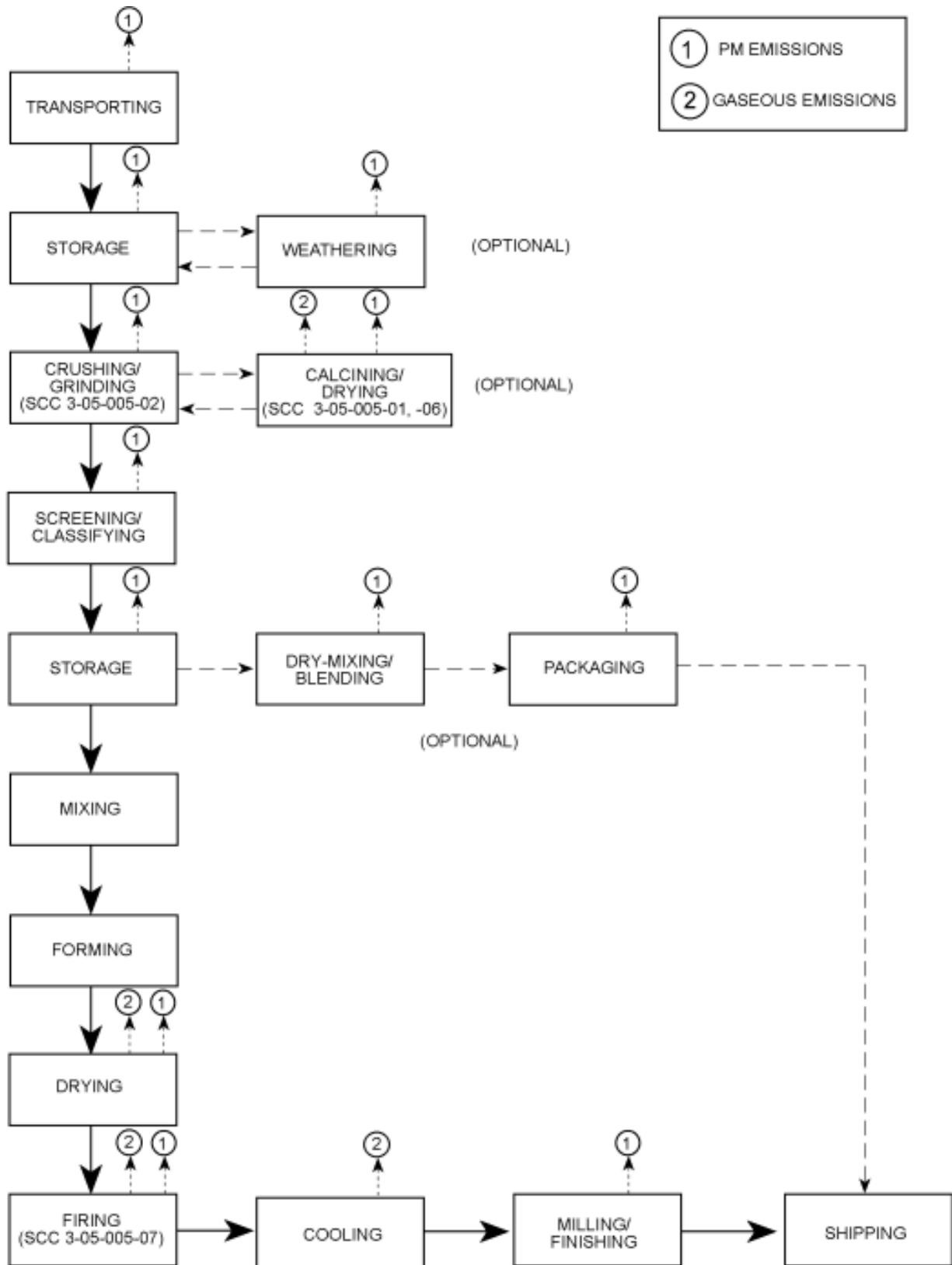


Figure 2-1. Refractory manufacturing process flow diagram.<sup>1</sup>

## 11.5 Refractory Manufacturing

### 11.5.1 Process Description<sup>1-2</sup>

Refractories are materials that provide linings for high-temperature furnaces and other processing units. Refractories must be able to withstand physical wear, high temperatures (above 538EC [1000EF]), and corrosion by chemical agents. There are two general classifications of refractories, clay and nonclay. The six-digit source classification code (SCC) for refractory manufacturing is 3-05-005. Clay refractories are produced from fireclay (hydrous silicates of aluminum) and alumina (57 to 87.5 percent). Other clay minerals used in the production of refractories include kaolin, bentonite, ball clay, and common clay. Nonclay refractories are produced from a composition of alumina (<87.5 percent), mullite, chromite, magnesite, silica, silicon carbide, zircon, and other nonclays.

Refractories are produced in two basic forms, formed objects, and unformed granulated or plastic compositions. The preformed products are called bricks and shapes. These products are used to form the walls, arches, and floor tiles of various high-temperature process equipment. Unformed compositions include mortars, gunning mixes, castables (refractory concretes), ramming mixes, and plastics. These products are cured in place to form a monolithic, internal structure after application.

Refractory manufacturing involves four processes: raw material processing, forming, firing, and final processing. Figure 11.5-1

illustrates the refractory manufacturing process. Raw material processing consists of crushing and grinding raw materials, followed if necessary by size classification and raw materials calcining and drying. The processed raw material then may be dry-mixed with other minerals and chemical compounds, packaged, and shipped as product. All of these processes are not required for some refractory products.

Forming consists of mixing the raw materials and forming them into the desired shapes. This process frequently occurs under wet or moist conditions. Firing involves heating the refractory material to high temperatures in a periodic (batch) or continuous tunnel kiln to form the ceramic bond that gives the product its refractory properties. The final processing stage involves milling, grinding, and sandblasting of the finished product. This step keeps the product in correct shape and size after thermal expansion has occurred. For certain products, final processing may also include product impregnation with tar and pitch, and final packaging.

Two other types of refractory processes also warrant discussion. The first is production of fused products. This process involves using an electric arc furnace to melt the refractory raw materials, then pouring the melted materials into sand-forming molds. Another type of refractory process is ceramic fiber production. In this process, calcined kaolin is melted in an electric arc furnace. The molten clay is either fiberized in a blowchamber with a centrifuge device or is dropped into an air jet and immediately blown into fine strands. After the blowchamber, the ceramic fiber may then be conveyed to an oven for curing, which adds structural rigidity to the fibers. During the curing process, oils are used to lubricate both the fibers and the machinery used to handle and form the fibers. The production of ceramic fiber for refractory material is very similar to the production of mineral wool.

### 11.5.2 Emissions And Controls<sup>2-6</sup>

The primary pollutant of concern in refractory manufacturing is particulate matter (PM). Particulate matter emissions occur during the crushing, grinding, screening, calcining, and drying of the raw materials; the drying and firing of the unfired "green" refractory bricks, tar and pitch operations; and finishing of the refractories (grinding, milling, and sandblasting).

Emissions from crushing and grinding operations generally are controlled with fabric filters. Product recovery cyclones followed by wet scrubbers are used on calciners and dryers to control PM emissions from these sources. The primary sources of PM emissions are the refractory firing kilns and electric arc furnaces. Particulate matter emissions from kilns generally are not controlled. However, at least one refractory manufacturer currently uses a multiple-stage scrubber to control kiln emissions. Particulate matter emissions from electric arc furnaces generally are controlled by a baghouse. Particulate removal of 87 percent and fluoride removal of greater than 99 percent have been reported at one facility that uses an ionizing wet scrubber.

Pollutants emitted as a result of combustion in the calcining and kilning processes include sulfur dioxide (SO<sub>2</sub>), nitrogen oxides (NO<sub>x</sub>), carbon monoxide (CO), carbon dioxide (CO<sub>2</sub>), and volatile organic compounds (VOC). The emission of SO<sub>x</sub> is also a function of the sulfur content of certain clays and the plaster added to refractory materials to induce brick setting. Fluoride emissions occur during the kilning process because of fluorides in the raw materials. Emission factors for filterable PM, PM-10, SO<sub>2</sub>, NO<sub>x</sub>, and CO<sub>2</sub> emissions from rotary dryers and calciners processing fire clay are presented in Tables 11.5-1 and 11.5-2. Particle size distributions for filterable particulate emissions from rotary dryers and calciners processing fire clay are presented in Table 11.5-3.

Volatile organic compounds emitted from tar and pitch operations generally are controlled by incineration, when inorganic particulates are not significant. Based on the expected destruction of organic aerosols, a control efficiency in excess of 95 percent can be achieved using incinerators.

Chromium is used in several types of nonclay refractories, including chrome-magnesite, (chromite-magnesite), magnesia-chrome, and chrome-alumina. Chromium compounds are emitted from the ore crushing, grinding, material drying and storage, and brick firing and finishing processes used in producing these types of refractories. Tables 11.5-4 and 11.5-5 present emission factors for emissions of filterable PM, filterable PM-10, hexavalent chromium, and total chromium from the drying and firing of chromite-magnesite ore. The emission factors are presented in units of kilograms of pollutant emitted per megagram of chromite ore processed (kg/Mg CrO<sub>3</sub>) (pounds per ton of chromite ore processed [lb/ton CrO<sub>3</sub>]). Particle size distributions for the drying and firing of chromite-magnesite ore are summarized in Table 11.5-6.

A number of elements in trace concentrations including aluminum, beryllium, calcium, chromium, iron, lead, mercury, magnesium, manganese, nickel, titanium, vanadium, and zinc also are emitted in trace amounts by the drying, calcining, and firing operations of all types of refractory materials. However, data are inadequate to develop emission factors for these elements.

Emissions of PM from electric arc furnaces producing fused cast refractory material are controlled with baghouses. The efficiency of the fabric filters often exceeds 99.5 percent. Emissions of PM from the ceramic fiber process also are controlled with fabric filters, at an efficiency similar to that found in the fused cast refractory process. To control blowchamber emissions, a fabric filter is used to remove small

pieces of fine threads formed in the fiberization stage. The efficiency of fabric filters in similar control devices exceeds 99 percent. Small particles of ceramic fiber are broken off

or separated during the handling and forming of the fiber blankets in the curing oven. An oil is used in this process, and higher molecular weight organics may be emitted. However, these emissions generally are controlled with a fabric filter followed by incineration, at an expected overall efficiency in excess of 95 percent.

Table 11.5-1 (Metric Units). EMISSION FACTORS FOR REFRACTORY MANUFACTURING: FIRE CLAY<sup>a</sup>

EMISSION FACTOR RATING: D

Process	SO <sub>2</sub>	NO <sub>x</sub>	CO <sub>2</sub>	Filterable <sup>b</sup>	
				PM	PM-10
Rotary dryer <sup>c</sup> (SCC 3-05-005-01)	ND	ND	15	33	8.1
Rotary dryer with cyclone (SCC 3-05-005-01)	ND	ND	15	5.6	2.6
Rotary dryer with cyclone and wet scrubber <sup>c</sup> (SCC 3-05-005-01)	ND	ND	15	0.052	ND
Rotary calciner (SCC 3-05-005-06)	ND	ND	300 <sup>c</sup>	62 <sup>d</sup>	14 <sup>e</sup>
Rotary calciner with multiclone (SCC 3-05-005-06)	ND	ND	300 <sup>c</sup>	31 <sup>f</sup>	ND
Rotary calciner with multiclone and wet scrubber (SCC 3-05-005-06)	3.8 <sup>d</sup>	0.87 <sup>d</sup>	300 <sup>c</sup>	0.15 <sup>d</sup>	0.031 <sup>e</sup>

<sup>a</sup> Factors represent uncontrolled emissions, unless noted. All emission factors in kg/Mg of raw material feed. SCC = Source Classification Code. ND = no data.

<sup>b</sup> 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.

<sup>c</sup> Reference 3.

<sup>d</sup> References 4-5.

<sup>e</sup> Reference 4.

<sup>f</sup> Reference 5.

Table 11.5-2 (English Units). EMISSION FACTORS FOR REFRACTORY MANUFACTURING:  
FIRE CLAY<sup>a</sup>

EMISSION FACTOR RATING: D

Process	SO <sub>2</sub>	NO <sub>x</sub>	CO <sub>2</sub>	Filterable <sup>b</sup>	
				PM	PM-10
Rotary dryer <sup>c</sup> (SCC 3-05-005-01)	ND	ND	30	65	16
Rotary dryer with cyclone <sup>c</sup> (SCC 3-05-005-01)	ND	ND	30	11	5.1
Rotary dryer with cyclone and wet scrubber <sup>c</sup> (SCC 3-05-005-01)	ND	ND	30	0.11	ND
Rotary calciner (SCC 3-05-005-06)	ND	ND	600 <sup>c</sup>	120 <sup>d</sup>	30 <sup>e</sup>
Rotary calciner with multiclone (SCC 3-05-005-06)	ND	ND	600 <sup>c</sup>	61 <sup>f</sup>	ND
Rotary calciner with multiclone and wet scrubber (SCC 3-05-005-06)	7.6 <sup>d</sup>	1.7 <sup>d</sup>	ND	0.30 <sup>d</sup>	0.062 <sup>e</sup>

<sup>a</sup> Factors represent uncontrolled emissions, unless noted. All emission factors in lb/ton of raw material feed. SCC = Source Classification Code. ND = no data.

<sup>b</sup> 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.

<sup>c</sup> Reference 3.

<sup>d</sup> References 4-5.

<sup>e</sup> Reference 4.

<sup>f</sup> Reference 5.

Table 11.5-3. PARTICLE SIZE DISTRIBUTIONS FOR REFRACTORY MANUFACTURING: FIRE CLAY<sup>a</sup>

EMISSION FACTOR RATING: D

Diameter (µm)	Uncontrolled	Multiclone Controlled	Cyclone Controlled	Cyclone/Scrubber Controlled
	Cumulative % Less Than Diameter			
Rotary Dryers (SCC 3-05-005-01) <sup>b</sup>				
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 3-05-005-06) <sup>c</sup>				
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

<sup>a</sup> For filterable PM only. ND = no data. SCC = Source Classification Code.

<sup>b</sup> Reference 3.

<sup>c</sup> References 4-5 (uncontrolled). Reference 4 (multiclone-controlled). Reference 5 (cyclone/scrubber-controlled).

Table 11.5-4 (Metric Units). EMISSION FACTORS FOR REFRACTORY MANUFACTURING:  
CHROMITE-MAGNESITE ORE<sup>a</sup>

EMISSION FACTOR RATING: D (except as noted)

Process	Filterable <sup>b</sup>		Chromium <sup>c</sup>	
	PM	PM-10	Hexavalent	Total
Rotary dryer (SCC 3-05-005-08)	0.83	0.20	3.8x10 <sup>-5</sup>	0.035
Rotary dryer with cyclone and fabric filter (SCC 3-05-005-08)	0.15	ND	1.9x10 <sup>-5</sup>	0.064
Tunnel kiln (SCC 3-05-005-09)	0.41	0.34	0.0087	0.13

<sup>a</sup> Reference 6. Factors represent uncontrolled emissions. Factors for filterable PM are kg/Mg of material processed. Factors for chromium are kg/Mg of chromite ore processed. SCC = Source Classification Code for chromium. ND = no data.

<sup>b</sup> 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 and filterable PM emission factor.

<sup>c</sup> EMISSION FACTOR RATING: E.

Table 11.5-5 (English Units). EMISSION FACTORS FOR REFRACTORY MANUFACTURING:  
CHROMITE-MAGNESITE ORE<sup>a</sup>

EMISSION FACTOR RATING: D (except as noted)

Process	Filterable <sup>b</sup>		Chromium <sup>c</sup>	
	PM	PM-10	Hexavalent	Total
Rotary dryer (SCC 3-05-005-08)	1.7	0.41	7.6x10 <sup>-5</sup>	0.70
Rotary dryer with cyclone and fabric filter (SCC 3-05-005-08)	0.30	ND	3.7x10 <sup>-5</sup>	0.13
Tunnel kiln (SCC 3-05-005-09)	0.82	0.69	0.017	0.27

<sup>a</sup> Reference 6. Factors represent uncontrolled emissions. Factors for filterable PM are lb/ton of material processed. Factors for chromium are lb/ton of chromite ore processed. SCC = Source Classification Code. ND = no data.

<sup>b</sup> 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 and filterable PM emission factor.

<sup>c</sup> EMISSION FACTOR RATING: E.

Table 11.5-6. PARTICLE SIZE DISTRIBUTIONS FOR REFRACTORY MANUFACTURING:  
CHROMITE-MAGNESITE ORE DRYING AND FIRING<sup>a</sup>

Diameter (µm)	Filterable PM <sup>b</sup>	Hexavalent Chromium <sup>c</sup>	Total Chromium <sup>c</sup>
	Cumulative % Less Than Diameter	Cumulative % Less Than Diameter	Cumulative % Less Than Diameter
Uncontrolled rotary dryer (SCC 3-05-005-01)			
1	1.2	3.5	0.8
2	13	39	9
10	24	64	19
Uncontrolled tunnel kiln (SCC 3-05-005-07)			
1	71	71	84
5	78	81	91
10	84	84	93

<sup>a</sup> Reference 6. For filterable PM only. SCC = Source Classification Code.

<sup>b</sup> EMISSION FACTOR RATING: D.

<sup>c</sup> EMISSION FACTOR RATING: E.

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