Emission Factor Documentation for AP-42
Section 9.13.2

Coffee Roasting

Final Report

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

EPA Contract 68-D2-0159
Work Assignment No. II-03

MRI Project No. 4602-03

September 1995

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Emission Factor and Inventory Group
Research Triangle Park, NC 27711

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NOTICE

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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. II-03. Mr. Dallas Safriet was the requester of the work.

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1. INTRODUCTION

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

An emission factor is a representative value that attempts to relate the quantity of a pollutant released to the atmosphere with an activity associated with the release of that pollutant. Emission factors usually are expressed as the weight of pollutant divided by the unit weight, volume, distance, or duration of the activity that emits the pollutant. The emission factors presented in AP-42 may be appropriate to use in a number of situations, such as making source-specific emission estimates for areawide inventories for dispersion modeling, developing control strategies, screening sources for compliance purposes, establishing operating permit fees, and making permit applicability determinations. The purpose of this report is to provide background information from test reports and other information to support revisions to AP-42 Section 6.2, Coffee Roasting.

This background report consists of five sections. Section 1 includes the introduction to the report. Section 2 gives a description of the coffee roasting industry. It includes a characterization of the industry, a description of the different process operations, a characterization of emission sources and pollutants emitted, and a description of the technology used to control emissions resulting from these sources. Section 3 is a review of emission data collection (and emission measurement) procedures. It describes the literature search, the screening of emission data reports, and the quality rating system for both emission data and emission factors. Section 4 details how the revised AP-42 section was developed. It includes the review of specific data sets, a description of how candidate emission factors were developed, and a summary of changes to the AP-42 section. Section 5 presents the AP-42 Section 9.13.2, Coffee Roasting.

2. INDUSTRY DESCRIPTION

2.1 INDUSTRY CHARACTERIZATION[1]

The coffee roasting industry involves the processing of green coffee beans into roasted coffee products, including whole and ground beans and soluble coffee products. The Standard Industrial Classification (SIC) code for coffee roasting is 2095, and the six-digit Source Classification Code (SCC) for the industry is 3-02-002. The six-digit SCC for instant coffee production is 3-02-003.

In 1987, 141 coffee roasting facilities were operating in the United States. The total value of shipments in the industry in 1987 was $6.4 billion; States that produced the most roasted coffee were California, New Jersey, Florida, and Texas.

2.2 PROCESS DESCRIPTION[2-7]

The coffee roasting process consists essentially of cleaning, roasting, cooling, grinding, and packaging operations. Figure 2-1 shows a process flow diagram for a typical coffee roasting operation. Bags of green coffee beans are hand- or machine-opened, dumped into a hopper, and screened to remove debris. The green beans are then weighed and transferred by belt or pneumatic conveyor to storage hoppers. From the storage hoppers, the green beans are conveyed to the roaster. Roasters typically operate at temperatures between 370° and 540°C (698° and 1004°F), and the beans are roasted for a period of time ranging from a few minutes to about 30 minutes. Roasters are typically horizontal rotating drums that tumble the green coffee beans in a current of hot air; the roasters operate in either batch or continuous modes. At the end of the roasting cycle, water sprays are used to "quench" the beans. Following roasting, the beans are cooled and run through a "destoner". Destoners are air classifiers that remove stones, metal fragments, and other waste not removed during initial screening from the beans. The destoners pneumatically convey the beans to a hopper, where the beans are stabilize and dry (small amounts of water from quenching exist on the surface of the beans). This stabilization process is called equilibration. Following equilibration, the roasted beans are ground, usually by multi-stage grinders. Some roasted beans are packaged and shipped as whole beans. Finally, the ground coffee is vacuum sealed and shipped.

Additional operations associated with processing green coffee beans include decaffeination and instant (soluble) coffee production. Decaffeination is the process of extracting caffeine from green coffee beans prior to roasting. The most common decaffeination process used in the United States is supercritical carbon dioxide (CO_2) extraction. In this process, moistened green coffee beans are contacted with large quantities of supercritical CO_2 (CO_2 maintained at a pressure of about 4000 pounds per square inch and temperatures between 90° and 100°C [194° and 212°F]), which removes about 97 percent of the caffeine from the beans. The caffeine is then recovered from the CO_2, typically using an activated carbon adsorption system. Another commonly used method is solvent extraction, typically using oil (extracted from roasted coffee) or ethyl acetate as a solvent. In this process, solvent is added to moistened green coffee beans to extract most of the caffeine from the beans. After the beans are removed from the solvent, they are steam-stripped to remove any residual solvent. The caffeine is then recovered from the solvent, and the solvent is re-used. Water extraction is also used for decaffeination, but little information on this process is available. Decaffeinated coffee beans have a residual caffeine content of about 0.1 percent on a dry basis. Not all facilities have decaffeination operations, and decaffeinated green coffee beans are purchased by many facilities that produce decaffeinated coffee.

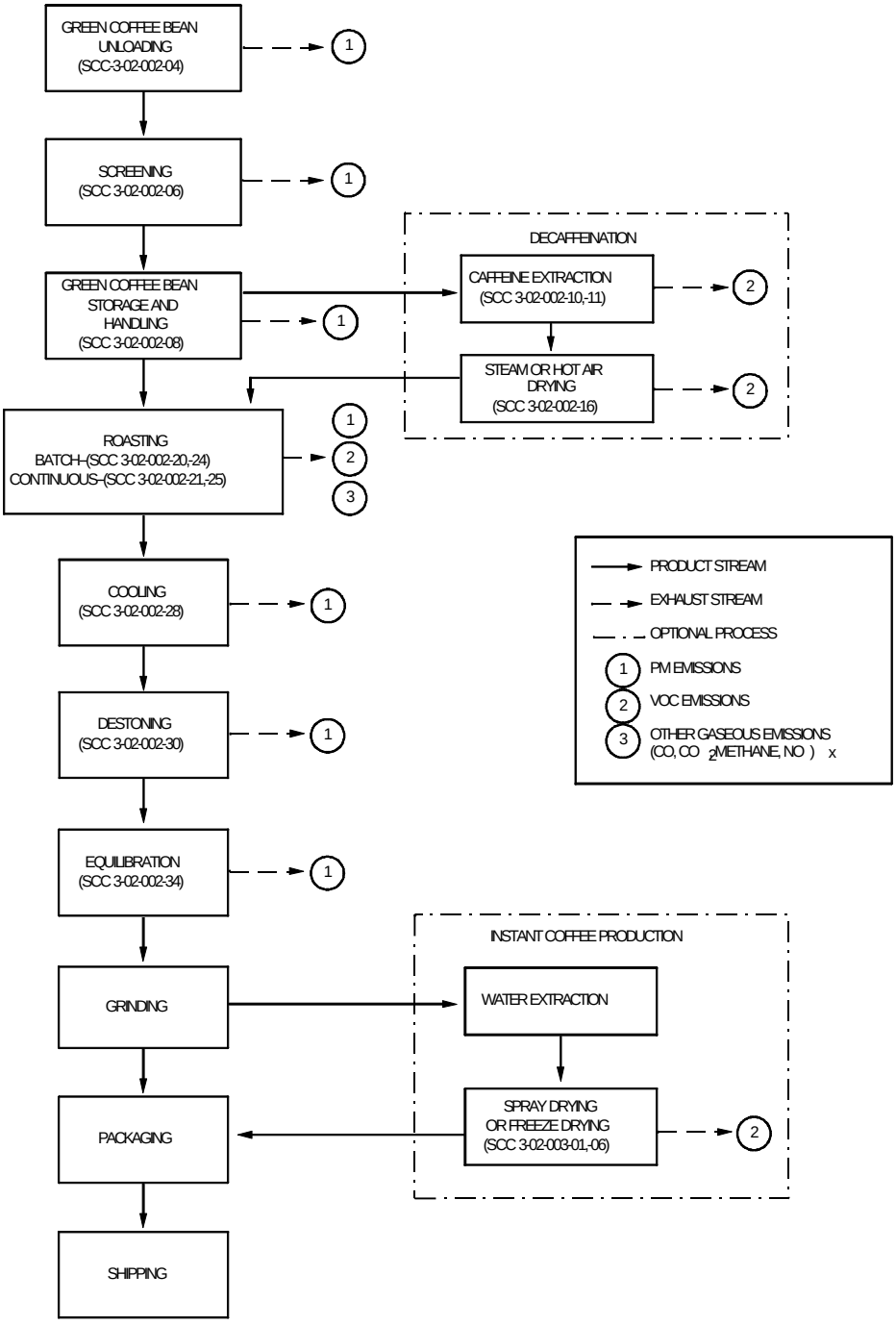

Figure 2-1. Typical coffee roasting operation.

In the manufacture of instant coffee, extraction follows the roasting and grinding operations. The soluble solids and volatile compounds that provide aroma and flavor are extracted from the coffee beans using water. Water heated to about 175°C (347°F) under pressurized conditions (to maintain the water as liquid) is used to extract all of the necessary solubles from the coffee beans. Manufacturers use both batch and continuous extractors. Following extraction, evaporation or freeze-concentration is used to increase the solubles concentration of the extract. The concentrated extracts are then dried in either spray dryers or freeze dryers. Information on the spray drying and freeze drying processes is not available.

2.3 EMISSIONS

Particulate matter (PM), volatile organic compounds (VOC), organic acids, and combustion products are the principal emissions from coffee processing. Several operations are sources of PM emissions, including the cleaning and destoning equipment, roaster, cooler, and instant coffee drying equipment. The roaster is the main source of gaseous pollutants, including alcohols, aldehydes, organic acids, and nitrogen and sulfur compounds. Because roasters are typically natural gas-fired, carbon monoxide (CO) and carbon dioxide (CO_2) emissions are expected as a result of combustion of natural gas. Decaffeination and instant coffee extraction and drying operations may also be sources of VOCs. Emissions from the grinding and packaging operations typically are not vented to the atmosphere.

2.4 EMISSION CONTROL TECHNOLOGY

Particulate matter emissions from the receiving, storage, cleaning, roasting, cooling, and stoning operations are typically ducted to cyclones before being emitted to the atmosphere. Gaseous emissions from roasting operations are typically ducted to a thermal oxidizer following PM removal by a cyclone. Some facilities use the burners that heat the roaster for destruction of VOC from roasting operations. However, separate thermal oxidizers are more efficient because the desired operating temperature is between 650°C (1200°F) and 816°C (1500°F), which is about 93°C (200°F) to 260°C (500°F) more than the maximum temperature of most roasters. Some facilities use thermal catalytic oxidizers, which require lower operating temperatures to achieve control efficiencies that are equivalent to standard thermal oxidizers. Catalysts are also used to improve the control efficiency of systems in which the roaster exhaust is ducted to the burners that heat the roaster. Emissions from spray dryers are typically controlled by a cyclone followed by a wet scrubber.

REFERENCES FOR SECTION 2

1. *1987 Census of Manufactures, Industry Series,* U.S. Department of Commerce, Washington, D.C., April 1990.

2. M. N. Clifford and K. C. Willson, *COFFEE--Botany, Biochemistry and Production of Beans and Beverage,* The AVI Publishing Company, Inc., Westport, CT, 1985.

3. R. G. Ostendorf (ed.), "Coffee Processing", *Air Pollution Engineering Manual,* Van Nostrand Reinhold, New York, NY, 1992.

4. J. M. L. Penninger, *Supercritical Fluid Technology--Potential In The Fine Chemicals And Pharmaceutical Industry*, Presented at the Workshop on Prevention of Waste and Emissions in the Fine Chemicals/Pharmaceutical Industry, Cork, Ireland, October 1993.

5. Telephone communication between B. Shrager, Midwest Research Institute, Cary, NC, and M. Wood, Tetley's Corporation, Palisades Park, NJ, December 20, 1994.

6. R. J. Clarke and R. MacRae, editors, *Coffee, Volume 2: Technology*, Elsevier Science Publishing Company, Inc., New York, NY, 1987.

7. G. Wasserman et al, "Coffee," *Kirk-Othmer Encyclopedia of Chemical Technology*, 4th. Ed., Volume No. 6, John Wiley & Sons, Inc., 1992.

3. GENERAL DATA REVIEW AND ANALYSIS PROCEDURES

3.1 LITERATURE SEARCH AND SCREENING

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

Information on the industry, including number of plants, plant location, and annual production capacities, was obtained from the *Census of Manufactures* and other sources. The Aerometric Information Retrieval System (AIRS) data base also was searched for data on the number of plants, plant location, and estimated annual emissions of criteria pollutants. A number of sources of information were investigated specifically for emission test reports and data. A search of the Test Method Storage and Retrieval (TSAR) data base was conducted to identify test reports for sources within the coffee roasting industry. However, no reports were identified using the TSAR data base. The EPA library was searched for additional test reports. Using information obtained on plant locations, State and Regional offices were contacted about the availability of test reports. Publications lists from the Office of Research and Development (ORD) and Control Technology Center (CTC) were also searched for reports on emissions from the coffee roasting industry. In addition, representative trade associations, including the National Coffee Association, were contacted for assistance in obtaining information about the industry and emissions.

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

1. Emission data must be from a primary reference:

a. Source testing must be from a referenced study that does not reiterate information from previous studies.

b. The document must constitute the original source of test data. For example, a technical paper was not included if the original study was contained in the previous document. If the exact source of the data could not be determined, the document was eliminated.

2. The referenced study should contain test results based on more than one test run. If results from only one run are presented, the emission factors must be down rated.

3. The report must contain sufficient data to evaluate the testing procedures and source operating conditions (e.g., one-page reports were generally rejected).

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

3.2 DATA QUALITY RATING SYSTEM[1]

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

1. Test series averages reported in units that cannot be converted to the selected reporting units;

2. Test series representing incompatible test methods (i.e., comparison of EPA Method 5 front half with EPA Method 5 front and back half);

3. Test series of controlled emissions for which the control device is not specified;

4. Test series in which the source process is not clearly identified and described; and

5. Test series in which it is not clear whether the emissions were measured before or after the control device.

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

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

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

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

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

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

1. Source operation. The manner in which the source was operated is well documented in the report. The source was operating within typical parameters during the test.

2. Sampling procedures. The sampling procedures conformed to a generally acceptable methodology. If actual procedures deviated from accepted methods, the deviations are well documented. When this occurred, an evaluation was made of the extent to which such alternative procedures could influence the test results.

3. Sampling and process data. Adequate sampling and process data are documented in the report, and any variations in the sampling and process operation are noted. If a large spread between test results

cannot be explained by information contained in the test report, the data are suspect and are given a lower rating.

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

3.3 EMISSION FACTOR QUALITY RATING SYSTEM[1]

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

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

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

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

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

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

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

REFERENCE FOR SECTION 3

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

4. REVIEW OF SPECIFIC DATA SETS

4.1 INTRODUCTION

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

4.2 REVIEW OF SPECIFIC DATA SETS

Thirteen references were obtained and reviewed for use in developing revised emission factors from coffee roasting and processing operations. Reference 2 was not used for emission factor development because the process rates provided in the report are estimates, References 3 and 6 were not used for emission factor development because the sources tested are not typical of the industry, and Reference 10 was not used for emission factor development because no process data are provided in the report. The other references are described in the following subsections.

4.2.1 Reference 1

This test report documents a compliance test conducted at Premium Coffee in Wall, New Jersey, on January 14, 1987. A natural gas-fired continuous roaster equipped with a cyclone and a thermal oxidizer was tested for filterable PM and carbon dioxide (CO_2). New Jersey Air Test Method 5, which is equivalent to EPA Method 5 (front-half analysis only), was used to measure PM emissions at the thermal oxidizer outlet, and either a Fyrite or Orsat gas analyzer was used to quantify CO_2 emissions at the same location. Three isokinetic test runs were conducted, and an average process rate (pounds of green coffee bean feed per hour) was provided. The roaster was operating at 67.5 percent of capacity during testing, and the thermal oxidizer was operating at between 704° and 760°C (1300° and 1400°F) during testing.

The filterable PM data from this test are assigned a B rating because the process was operating at only 67.5 percent of capacity during testing. The test methodology appeared to be sound, no problems were reported, and adequate detail was provided in the report. The CO_2 data are assigned a C rating because the test method was not specified. Report excerpts and emission factor calculations are included in Appendix A.

4.2.2 Reference 3

This test report documents a compliance test conducted at General Foods Corporation, Maxwell House Division in Hoboken, New Jersey, on September 9, 1987. A continuous coffee bean cooler equipped with a cyclone was tested for filterable PM and CO_2. New Jersey Air Test Method 5 was used to measure PM emissions at the rotoclone inlet and outlet (an Orsat gas analyzer did not detect CO_2 at these locations). Three isokinetic test runs were conducted, and process rates (assumed to represent pounds of green coffee beans fed to the continuous roaster per hour) for each test run were provided. The cooler was operating near capacity during testing, and the cyclone provided about 93 percent control of PM emissions from the cooler during testing. The results of Run 3 (inlet) presented in the report were corrected because of an error in the test report calculations.

The data from this test are note rated for use in developing emission factors because the cooler is part of a pilot plant and probably is not typical of the industry.

4.2.3 Reference 4

This test report documents a compliance test conducted at Hills Brothers Coffee, Incorporated, in Edgewater, New Jersey, on August 31, 1988. Roaster stack number 23, which vents emissions from a natural gas-fired continuous roaster equipped with a thermal oxidizer, was tested for filterable PM, total hydrocarbons (THC) as methane, CO, and CO_2. New Jersey Air Test Methods 5 and 3 (which is similar to EPA Method 25A) were used to measure PM and THC emissions, respectively, at the thermal oxidizer inlet and outlet. In addition, an Orsat gas analyzer was used to quantify CO_2 emissions at these locations, and CO emissions were quantified using EPA Method 10 (integrated sample). Three isokinetic test runs were conducted at the inlet and outlet, and an average process rate (pounds of green coffee bean feed per minute) was provided. The thermal oxidizer operating temperature was not included in the report.

The data from this test are assigned an A rating. The test methodology appeared to be sound, no problems were reported, and adequate detail was provided in the report. Report excerpts and emission factor calculations are included in Appendix B.

4.2.4 Reference 5

This test report documents a compliance test conducted at Hills Brothers Coffee, Incorporated, in Edgewater, New Jersey, on September 15, 1988. Roaster stack number 22, which vents emissions from a natural gas-fired continuous roaster equipped with a thermal oxidizer, was tested for filterable PM, THC as methane, CO, and CO_2. New Jersey Air Test Methods 5 and 3 were used to measure PM and THC emissions at the thermal oxidizer inlet and outlet, and an Orsat gas analyzer was used to quantify CO_2 emissions at these locations. Carbon monoxide emissions were quantified using EPA Method 10 (integrated sample). Three isokinetic test runs were conducted at the inlet and outlet, and an average process rate (pounds of green coffee bean feed per minute) was provided. The thermal oxidizer operating temperature was not included in the report.

The data from this test are assigned an A rating. The test methodology appeared to be sound, no problems were reported, and adequate detail was provided in the report. Report excerpts and emission factor calculations are included in Appendix C.

4.2.5 Reference 6

This test report documents a compliance test conducted at General Foods Corporation, Maxwell House Division in Hoboken, New Jersey, on January 31 and February 1, 1989. Two natural gas-fired pilot plant roasters equipped with a thermal oxidizer were tested for filterable PM, THC as methane, CO, and CO_2. New Jersey Air Test Method 5 was used to measure PM emissions at the thermal oxidizer inlet and outlet, and an Orsat gas analyzer was used to quantify CO_2 emissions at these locations. Carbon dioxide was not detected at the thermal oxidizer inlet. New Jersey Air Test Method 3 and EPA Method 10 were used to quantify THC and CO emissions, respectively, at the thermal oxidizer outlet. Three isokinetic test runs were conducted at the inlet and outlet, and an average process rate (pounds of green coffee bean feed per minute) was provided. The thermal oxidizer was operating at about 816°C (1500°F) during testing.

The data from this test are not rated for use in developing emission factors because the roasters are part of a pilot plant and probably are not typical of the industry.

4.2.6 Reference 7

This test report documents a compliance test conducted at Nestle Food Corporation in Freehold, New Jersey, on August 10, 1990. Three natural gas-fired continuous roasters equipped with a thermal oxidizer were tested for filterable PM, THC as methane, CO, and CO_2. New Jersey Air Test Method 3 was used to measure THC emissions at the thermal oxidizer inlet and outlet, and an Orsat gas analyzer was used to quantify CO_2 emissions at these locations. New Jersey Air Test Method 1 (equivalent to EPA Method 5--front-half) and EPA Method 10 were used to quantify PM and CO emissions, respectively, at the thermal oxidizer outlet. Three test runs were conducted at the inlet and outlet, and an average process rate (pounds of green coffee bean feed per minute) was provided. The thermal oxidizer was operating at about 816°C (1500°F) during testing.

The data from this test are assigned an A rating. The test methodology appeared to be sound, no problems were reported, and adequate detail was provided in the report. Report excerpts and emission factor calculations are included in Appendix D.

4.2.7 Reference 8

This test report documents a compliance test conducted at General Foods Corporation, Maxwell House Division, in Hoboken, New Jersey, on December 20, 1990. A natural gas-fired batch roaster (7D) equipped with a thermal oxidizer was tested for filterable PM, THC as methane, CO, and CO_2 using EPA Methods 5, 25A, 10, and 3A (with Orsat gas analyzer), respectively. Three test runs were conducted at the thermal oxidizer outlet, and process rates (pounds of green coffee bean feed per minute) were provided for each test run. The thermal oxidizer was operating at temperatures in excess of 816°C (1500°F) during testing.

The data from this test are assigned an A rating. The test methodology appeared to be sound, no problems were reported, and adequate detail was provided in the report. Report excerpts and emission factor calculations are included in Appendix E.

4.2.8 Reference 9

This test report documents a compliance test conducted at General Foods Corporation, Maxwell House Division, in Hoboken, New Jersey, on May 9, 1991. The same natural gas-fired batch roaster described in Reference 8 was tested for THC as methane and CO using EPA Methods 25A and 10, respectively. Four test runs were conducted at the thermal oxidizer outlet, and process rates (pounds of green coffee bean feed per minute) were provided for each test run. Run 1 was voided because of problems with the sampling train. The thermal oxidizer was operating at temperatures in excess of 816°C (1500°F) during testing.

The data from this test are assigned an A rating. The test methodology appeared to be sound, no problems were reported, and adequate detail was provided in the report. Report excerpts and emission factor calculations are included in Appendix F.

4.2.9 Reference 11

This test report documents a compliance test conducted at Melitta, Incorporated, in Cherry Hill, New Jersey, on January 7, 1992. A natural gas-fired batch roaster equipped with a thermal oxidizer was tested for filterable PM, THC as methane, CO, and CO_2. New Jersey Air Test Method 3-7 (GC/FID) was used to measure THC emissions at the thermal oxidizer inlet and outlet. Carbon dioxide concentrations at the inlet were measured using EPA Method 3 (with Orsat gas analyzer), and outlet CO_2 emissions were quantified using EPA Method 3A. New Jersey Air Test Method 1 and EPA Method 10 were used to quantify PM and CO emissions, respectively, at the thermal oxidizer outlet. Three test runs were conducted at the inlet and outlet, and process rates (pounds of green coffee bean feed per minute) were provided for each test run. The thermal oxidizer was operating at about 816°C (1500°F) during testing.

The data from this test are assigned an A rating. The test methodology appeared to be sound, no problems were reported, and adequate detail was provided in the report. Report excerpts and emission factor calculations are included in Appendix G.

4.2.10 Reference 12

This test report documents a compliance test conducted at Nestle Beverage Company in Union City, California, on September 18, 1992. A continuous roaster equipped with a thermal catalytic oxidizer was tested for filterable PM, condensible PM, total nonmethane hydrocarbons (TNMHC) as methane, CO, and CO_2 emissions. Bay Area Air Quality Management District (BAAQMD) Methods ST-5, ST-6, and ST-7 (continuous monitoring methods) were used to measure CO_2, CO, and TNMHC emissions, respectively, at the oxidizer inlet and outlet, and CARB Method 5 was used to quantify filterable and condensible PM emissions at these locations. The BAAQMD test methods are not described in detail in the report, but appear to be similar to EPA Methods for the pollutants measured. In addition, total PM emissions from the coffee bean cooler were measured using California Air Resources Board (CARB) Method 5. The control system (if any) on the cooler is not identified in the report; however, a BAAQMD representative stated that the cooler test was conducted at a location downstream of a cyclone. The PM measurements from Run 1 on the oxidizer inlet are not used because the probe and nozzle rinse portion appeared to be contaminated. Three test runs were conducted at all test locations, and an average process rate (pounds of green coffee bean feed per minute) was provided. The oxidizer was operating at about 411°C (772°F) during testing.

The data for continuous roaster emissions from this test (except for the oxidizer outlet PM data) are assigned an A rating. The test methodology appeared to be sound, no problems were reported, and adequate detail was provided in the report. The oxidizer outlet PM data are assigned a B rating because only two valid test runs were conducted. The continuous coffee bean cooler data are assigned a B rating because the control system on the cooler was not identified in the report. Report excerpts and emission factor calculations are included in Appendix H.

4.2.11 Reference 13

This test report summary documents a compliance test conducted at Hills Brothers Coffee Company in San Francisco, California, on January 10, 1991. The baghouse that controls PM emissions from the green coffee handling system was tested for total PM emissions using a Method 5 type sampling train. Three test runs were conducted, and an average process rate (pounds of green coffee bean feed per minute) was provided.

The data from this test are assigned a C rating. The test methodology appeared to be sound and no problems were reported. However, the green coffee handling system is not described in the report, and a process description is needed to accurately characterize emissions. The green bean handling system is assumed to include all preroasting operations, but the exact configuration of the system is not known. Report excerpts and emission factor calculations are included in Appendix I.

4.2.12 Review of FIRE and SPECIATE Data Base Emission Factors

The emission factors provided in FIRE are the same factors that are presented in the Coffee Roasting section of the 1972 version of AP-42. Most of the coffee roasting emission factors contained in SPECIATE are based on profiles that are not similar to coffee roasting operations. The other emission factors are the same factors that are presented in the Coffee Roasting section of the 1972 version of AP-42.

4.2.13 Review of Test Data in AP-42 Background File

No original test data was found in the background file. The emission factors presented in the current version of AP-42 are referenced to documents that do not contain any original test data, and appear to be based on pollutant concentrations presented in the referenced documents. The data appear to be based on tests and studies from the late 1940's, 1950's, and 1960's and are not considered valid for inclusion in the revised AP-42 section.

4.3 DEVELOPMENT OF CANDIDATE EMISSION FACTORS

TABLE 4-1. SUMMARY OF TEST DATA FOR COFFEE ROASTING[a]

Source	Pollutant	No. of test runs	Data rating	Emission factor range, kg/Mg (lb/ton)	Average emission factor, kg/Mg (lb/ton)	Ref. No.
Continuous roaster with thermal oxidizer	Filterable PM	3	B	0.0600-0.113 (0.120-0.225)	0.0915 (0.183)	1
Continuous roaster with thermal oxidizer	CO_2	3	C	154-162 (308-323)	158 (316)	1
Continuous cooler	Filterable PM	3	NR	0.610-2.18 (1.22-4.35)	1.22 (2.44)	3
Continuous cooler with cyclone	Filterable PM	3	NR	0.0770-0.106 (0.154-0.211)	0.0870 (0.174)	3
Continuous roaster	Filterable PM	3	A	0.252-0.356 (0.503-0.712)	0.289 (0.578)	4
Continuous roaster	VOC as methane[b]	3	A	0.388-1.17 (0.777-2.35)	0.702 (1.40)	4
Continuous roaster	CO	3	A	1.20-2.15 (0.600-1.08)	0.800 (1.60)	4
Continuous roaster	CO_2	3	A	54.0-72.5 (108-145)	60.6 (121)	4
Continuous roaster with thermal oxidizer	Filterable PM	3	A	0.00707-0.0263 (0.0141-0.0525)	0.0158 (0.0316)	4
Continuous roaster with thermal oxidizer	VOC as methane[b]	3	A	0.0680-0.145 (0.136-0.290)	0.106 (0.212)	4
Continuous roaster with thermal oxidizer	CO	3	A	0.00249-0.00404 (0.00497-0.00808)	0.00302 (0.00603)	4
Continuous roaster with thermal oxidizer	CO_2	3	A	0	0	4
Continuous roaster	Filterable PM	3	A	0.339-0.385 (0.678-0.771)	0.368 (0.736)	5
Continuous roaster	VOC as methane[b]	3	A	0.538-0.650 (1.08-1.29)	0.585 (1.17)	5
Continuous roaster	CO	3	A	0.530-0.560 (1.06-1.12)	0.548 (1.10)	5
Continuous roaster	CO_2	3	A	58.8-60.3 (118-121)	59.4 (119)	5
Continuous roaster with thermal oxidizer	Filterable PM	3	A	0.0216-0.0314 (0.0431-0.0627)	0.0265 (0.0529)	5

TABLE 4-1. (continued)

Source	Pollutant	No. of test runs	Data rating	Emission factor range, kg/Mg (lb/ton)	Average emission factor, kg/Mg (lb/ton)	Ref. No.
Continuous roaster with thermal oxidizer	VOC as methane[b]	3	A	0.0394-0.0955 (0.0788-0.191)	0.0586 (0.117)	5
Continuous roaster with thermal oxidizer	CO	3	A	0.0874-0.178 (0.175-0.356)	0.141 (0.282)	5
Continuous roaster with thermal oxidizer	CO_2	3	A	143-188 (286-375)	167 (334)	5
Continuous roaster	Filterable PM	3	NR	1.28-1.88 (2.55-3.76)	1.52 (3.03)	6
Continuous roaster with thermal oxidizer	Filterable PM	3	NR	0.343-0.800 (0.686-1.60)	0.562 (1.12)	6
Continuous roaster with thermal oxidizer	VOC as methane[b]	3	NR	0.286-0.514 (0.571-1.03)	0.410 (0.819)	6
Continuous roaster with thermal oxidizer	CO	3	NR	3.26-10.6 (6.51-21.1)	5.94 (11.9)	6
Continuous roaster with thermal oxidizer	CO_2	3	NR	2130-2310 (4250-4610)	2230 (4460)	6
Continuous roaster	VOC as methane[b]	3	A	0.263-0.286 (0.527-0.573)	0.273 (0.547)	7
Continuous roaster	CO_2	3	A	52.4-53.6 (105-107)	53.1 (106)	7
Continuous roaster with thermal oxidizer	Filterable PM	3	A	0.0381-0.0539 (0.0762-0.108)	0.0439 (0.0879)	7
Continuous roaster with thermal oxidizer	VOC as methane[b]	3	B	0.00183-0.00194 (0.00366-0.00388)	0.00190 (0.00379)	7[c]
Continuous roaster with thermal oxidizer	CO	3	A	0.0104-0.0310 (0.0208-0.0620)	0.0212 (0.0425)	7
Continuous roaster with thermal oxidizer	CO_2	3	A	5.46-8.12 (10.9-16.2)	7.05 (14.1)	7
Batch roaster with thermal oxidizer	Filterable PM	3	A	0.0777-0.0906 (0.155-0.181)	0.0850 (0.170)	8[d]
Batch roaster with thermal oxidizer	VOC as methane[b]	3	A	0.00382-0.00471 (0.00763-0.00941)	0.00417 (0.00833)	8[d]

TABLE 4-1. (continued)

Source	Pollutant	No. of test runs	Data rating	Emission factor range, kg/Mg (lb/ton)	Average emission factor, kg/Mg (lb/ton)	Ref. No.
Batch roaster with thermal oxidizer	CO	3	A	0.211-0.265 (0.423-0.530)	0.235 (0.471)	8[d]
Batch roaster with thermal oxidizer	CO_2	3	A	231-280 (462-560)	248 (497)	8[d]
Batch roaster with thermal oxidizer	VOC as methane[b]	3	A	0.00195-0.00505 (0.00390-0.0101)	0.00360 (0.00720)	9
Batch roaster with thermal oxidizer	CO	3	A	0.0867-0.109 (0.173-0.219)	0.0950 (0.190)	9
Batch roaster	VOC as methane[b]	3	A	0.266-0.518 (0.531-1.04)	0.430 (0.861)	11
Batch roaster	CO_2	3	A	69.9-127 (140-254)	90.3 (181)	11
Batch roaster with thermal oxidizer	Filterable PM	3	A	0.00621-0.0730 (0.0124-0.146)	0.0312 (0.0624)	11
Batch roaster with thermal oxidizer	VOC as methane[b]	3	A	0.0294-0.0550 (0.0588-0.110)	0.0433 (0.0865)	11
Batch roaster with thermal oxidizer	CO	3	A	0.286-0.570 (0.572-1.14)	0.389 (0.778)	11
Batch roaster with thermal oxidizer	CO_2	3	A	205-411 (411-823)	281 (562)	11
Continuous coffee cooler with cyclone	Filterable PM	3	B	0.00965-0.0166 (0.0193-0.0332)	0.0140 (0.0279)	12
Continuous roaster	Methane	3	A	0.225-0.235 (0.449-0.470)	0.231 (0.462)	12
Continuous roaster	VOC as methane[b]	3	A	0.950-1.34 (1.90-2.68)	1.21 (2.42)	12
Continuous roaster	CO	3	A	0.795-0.938 (1.59-1.88)	0.880 (1.76)	12
Continuous roaster	CO_2	3	A	67.8-68.8 (136-138)	68.3 (137)	12
Continuous roaster with thermal oxidizer[e]	Filterable PM	2	B	0.0440-0.0590 (0.0879-0.118)	0.0515 (0.103)	12
Continuous roaster with thermal oxidizer[e]	Condensible PM	2	B	0.0495-0.0526 (0.0991-0.105)	0.0511 (0.102)	12
Continuous roaster with thermal oxidizer[e]	Methane	3	A	0.146-0.161 (0.291-0.323)	0.154 (0.308)	12

Table 4-1. (continued)

Source	Pollutant	No. of test runs	Data rating	Emission factor range, kg/Mg (lb/ton)	Average emission factor, kg/Mg (lb/ton)	Ref. No.
Continuous roaster with thermal oxidizer[e]	VOC as methane[b]	3	A	0.150-0.167 (0.300-0.335)	0.161 (0.321)	12
Continuous roaster with thermal oxidizer[e]	CO	3	A	0.0280-0.0318 (0.0561-0.0635)	0.0300 (0.0599)	12
Continuous roaster with thermal oxidizer[e]	CO_2	3	A	119-129 (238-258)	125 (249)	12
Green coffee handling system with baghouse	Filterable PM	3	C	0.0252-0.0336 (0.0504-0.0672)	0.0294 (0.0588)	13

[a]Emission factors in units of pollutant mass per mass of green coffee bean feed, unless noted otherwise. Roasters are natural gas-fired.
[b]May include nonreactive compounds.
[c]VOC emissions were not detected in any test run and are estimated using one-half of the detection limit.
[d]The source is the same source tested in Reference 9.
[e]Control device is a thermal catalytic oxidizer.

summarizes the test data from the emission test reports presented in Section 4.2, and Table 4-2 Table 4.2

TABLE 4-2. SUMMARY OF EMISSION FACTORS FOR COFFEE ROASTING[a]

Source	Pollutant	No. of tests	Emission factor rating	Emission factor range, kg/Mg (lb/ton)	Average emission factor, kg/Mg (lb/ton)	Ref. Nos.
Batch roaster	CO_2	1	D	NA	90 (180)	11
Batch roaster	VOC as methane[b,c]	1	D	NA	0.43 (0.86)	11
Batch roaster with thermal oxidizer	CO	3	D	0.095-0.39 (0.19-0.78)	0.28 (0.55)	8,9,11
Batch roaster with thermal oxidizer	CO_2	2	D	250-280 (500-560)	260 (530)	8,11
Batch roaster with thermal oxidizer	Filterable PM	2	D	0.031-0.085 (0.062-0.17)	0.058 (0.12)	8,11
Batch roaster with thermal oxidizer	VOC as methane[b,c]	3	D	0.0036-0.043 (0.0072-0.087)	0.024 (0.047)	8,9,11
Continuous cooler with cyclone	Filterable PM	1	D	NA	0.014 (0.028)	12
Continuous roaster	CO	3	D	0.55-0.88 (1.1-1.8)	0.74 (1.5)	4,5,12
Continuous roaster	CO_2	4	C	53-68 (110-140)	60 (120)	4,5,7,12
Continuous roaster	Filterable PM	2	D	0.29-0.37 (0.58-0.74)	0.33 (0.66)	4,5
Continuous roaster	Methane	NA	E	NA	0.13 (0.26)	4,5,7,12
Continuous roaster	VOC as methane[b]	4	D	0.27-1.2 (0.55-2.4)	0.69 (1.4)	4,5,7,12
Continuous roaster with thermal oxidizer	CO	4	D	0.0030-0.14 (0.0060-0.28)	0.049 (0.098)	4,5,7,12
Continuous roaster with thermal oxidizer	CO_2	3	D	7.0-170 (14-330)	100 (200)	5,7,12
Continuous roaster with thermal oxidizer	Filterable PM	5	D	0.016-0.092 (0.032-0.18)	0.046 (0.092)	1,4,5,7,12
Continuous roaster with thermal oxidizer	Condensible PM	1	D	NA	0.051 (0.10)	12
Continuous roaster with thermal oxidizer	VOC as methane[b]	4	D	0.059-0.16 (0.12-0.32)	0.082 (0.16)	4,5,7,12
Continuous roaster with thermal oxidizer	Methane	NA	E	NA	0.078 (0.15)	4,5,7,12
Green coffee handling system with baghouse	Filterable PM	1	E	NA	0.029 (0.059)	13

[a]Emission factors in units of pollutant mass per mass of green coffee bean feed, unless noted otherwise. Roasters are natural gas-fired.

[b]May include nonreactive compounds.

[c]Methane emissions from uncontrolled continuous roasters are estimated to account for 19.1 percent of the total organic emissions (see Table 4-1). For controlled continuous roasters, methane emissions are estimated to account for 95.9 percent of the total organic emissions (see Table 4-1). It should be noted that the methane percentages are based on one E-rated emission test.

presents the emission factors developed using these data.

The emission factor ratings assigned to the factors for the revised AP-42 section are based on the guidelines presented in Section 3.3 of this report. The main criteria used in rating the factors are as follows:

1. Factors based on C- or D-rated data must be assigned a rating of E; and

2. Factors based on B-rated data or a combination of A- and B-rated data generally cannot be assigned a rating higher than C, and if the data are from a small number of facilities that are unlikely to represent a random sample of the industry, the factor generally is assigned a D rating.

Emission factors were developed by grouping the data from similar combinations of source, pollutant, and control device, discarding the inferior data sets, and averaging the emission factors derived from each data set. In some cases, data were available from multiple tests on the same source. In such cases, the emission factors from the tests on that source were averaged first, and the resulting factor was then averaged with the factors from other similar sources. The following paragraphs describe how the data presented in Table 4-1 were used to develop the emission factors presented in Table 4-2.

4.3.1 Batch Roasters

Emission factors for uncontrolled emissions from natural gas-fired batch roasters were developed using data from a single test (Reference 11). Emission factors for thermal oxidizer-controlled emissions from natural gas-fired batch roasters were developed using data from three tests conducted at two facilities (References 8, 9, and 11). All of the emission factors for batch roasters are assigned D ratings because data from only one or two facilities were used to develop the emission factors.

4.3.2 Continuous Coolers

An emission factor for cyclone-controlled filterable PM emissions from continuous coolers was developed using B-rated data from Reference 12. The filterable PM emission factor is assigned a D rating because it is based on data from a single test.

4.3.3 Continuous Roasters

Emission factors for uncontrolled and controlled emissions from natural gas-fired continuous roasters were developed from data from several tests. The pollutants measured were filterable PM, condensible PM, VOC, methane, CO, and CO_2. Data from Reference 12, which documents a test on a roaster controlled with a thermal catalytic oxidizer operating at temperatures of about 411°C (772°F), were similar to data for thermal oxidizers operating at temperatures of about 816°C (1500°F) and were combined with these data.

4.3.3.1 Filterable PM. Data from two A-rated and one unrated test are available for filterable PM emissions from uncontrolled continuous roasters. The two A-rated data sets were used to develop an average emission factor of 0.33 kg/Mg (0.66 lb/ton). This emission factor is assigned a D rating.

Data from three A-rated, two B-rated, and one unrated test are available for filterable PM emissions from continuous roasters controlled with thermal oxidizers. The A- and B-rated data sets, for

which emission factors ranged from 0.016 kg/Mg (0.032 lb/ton) to 0.092 kg/Mg (0.18 lb/ton), were used to develop an average emission factor of 0.046 kg/Mg (0.092 lb/ton). This emission factor is assigned a D rating.

4.3.3.2 Condensible PM. An emission factor for condensible PM emissions from continuous roasters controlled with thermal oxidizers was developed from data from a single B-rated test. This emission factor is assigned a D rating.

4.3.3.3 Volatile Organic Compounds. Data from four A-rated tests are available for VOC emissions from uncontrolled continuous roasters. The VOC emissions are expressed on an "as methane" basis. The data sets, for which emission factors ranged from 0.27 kg/Mg (0.55 lb/ton) to 1.2 kg/Mg (2.4 lb/ton), were used to develop an average emission factor of 0.69 kg/Mg (1.4 lb/ton). This emission factor is assigned a D rating.

Data from four A-rated tests and one unrated test are available for VOC emissions from continuous roasters controlled with thermal oxidizers. The VOC emissions are expressed on an "as methane" basis. The A-rated data sets, for which emission factors ranged from 0.0019 kg/Mg (0.0038 lb/ton) to 0.16 kg/Mg (0.32 lb/ton), were used to develop an average emission factor of 0.082 kg/Mg (0.16 lb/ton). This emission factor is assigned a D rating because the data range over two orders of magnitude.

4.3.3.4 Methane. Emission factors for methane emissions from continuous roasters (uncontrolled and controlled with thermal oxidizers) were calculated by multiplying the ratio of methane to VOC (from Reference 12) by the average VOC emission factors described in Section 4.3.3.3 of this report. Reference 12 data indicate that 19.1 percent of uncontrolled VOC emissions are methane. The resulting uncontrolled methane emission factor is 19.1 percent of the uncontrolled VOC emission factor, or 0.13 kg/Mg (0.26 lb/ton). For controlled emissions, Reference 12 data indicate that about 95.9 percent of VOC emissions are methane. The resulting methane emission factor is 95.9 percent of the controlled VOC emission factor, or 0.078 kg/Mg (0.15 lb/ton). These emission factors are assigned an E rating.

4.3.3.5 Carbon Monoxide. Data from three A-rated tests are available for CO emissions from uncontrolled continuous roasters. The data sets, for which emission factors ranged from 0.55 kg/Mg (1.1 lb/ton) to 0.88 kg/Mg (1.8 lb/ton), were used to develop an average emission factor of 0.74 kg/Mg (1.5 lb/ton). This emission factor is assigned a D rating because it is based on data from only three facilities.

Data from four A-rated and one unrated test are available for CO emissions from continuous roasters controlled with thermal oxidizers. The A-rated data sets, for which emission factors ranged from 0.0030 kg/Mg (0.0060 lb/ton) to 0.14 kg/Mg (0.28 lb/ton), were used to develop an average emission factor of 0.049 kg/Mg (0.098 lb/ton). This emission factor is assigned a D rating because the data range over almost two orders of magnitude.

4.3.3.6 Carbon Dioxide. Data from four A-rated tests are available for CO_2 emissions from uncontrolled continuous roasters. The data sets, for which emission factors ranged from 53 kg/Mg (110 lb/ton) to 68 kg/Mg (140 lb/ton), were used to develop an average emission factor of 60 kg/Mg (120 lb/ton). This emission factor is assigned a C rating because it is based on data from only four facilities.

Data from three A-rated, one C-rated, and one unrated test are available for CO_2 emissions from continuous roasters controlled with thermal oxidizers. The three A-rated data sets, for which emission factors ranged from 7.1 kg/Mg (14 lb/ton) to 170 kg/Mg (330 lb/ton), were used to develop an average emission factor of 100 kg/Mg (200 lb/ton). This emission factor is assigned a D rating because the data range over an order of magnitude.

4.3.4 Green Coffee Handling System

An emission factor for filterable PM emissions from a fabric filter-controlled green coffee handling system was developed from C-rated data from a single test (Reference 13). This system is assumed to include green bean screening, handling, and storage operations; the actual configuration of the system is not known. This emission factor is assigned an E rating because it is based on C-rated data from a single test.

4.4 SUMMARY OF CHANGES TO AP-42 SECTION

4.4.1 Section Narrative

The section narrative was revised to include a more detailed process description and discussion of emissions and controls. A process flow diagram for a typical coffee processing facility was also developed.

4.4.2 Emission Factors

The emission factor tables for the AP-42 section were completely revised to incorporate the emission factors developed from the new test data. The previous versions of the section presented emission factors for PM, nitrogen oxides (NO_x), aldehydes, and organic acids from uncontrolled roasters. Also presented were PM emission factors for uncontrolled "stoner and cooler" emissions, as well as emissions from instant coffee spray dryers controlled with a cyclone and wet scrubber. The revised section includes emission factors for filterable PM, condensible PM, VOC, methane, CO, and CO_2. The previous AP-42 section presented factors for uncontrolled emissions only, except for the spray dryer emission factor. The revised section presents uncontrolled and controlled factors for batch and continuous roasters. All of the roasters are assumed to be indirect-fired because the roaster type was not specified in any of the reports.

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3. *Stack Sampling Report For General Foods Corporation, Maxwell House Division, Hoboken, New Jersey, On Rotoclone Inlet And Outlet*, Recon Systems, Inc., Three Bridges, NJ, September 9, 1987.

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8. *Source Test Report For Particulate, Volatile Organic Compounds, And Carbon Monoxide Emissions From The Coffee Roaster 7D Thermal oxidizer At General Foods-Maxwell House Division, Hoboken, New Jersey*, Air Consulting and Engineering, Inc., Gainesville, FL, December 20, 1990.

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