Emission Factor Documentation for AP-42
Section 10.7

Charcoal

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-04

MRI Project No. 4602-04

September 1995

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

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NOTICE

The information in this document has been funded wholly or in part by the United States Environmental Protection Agency under Contract No. 68-D2-0159 to Midwest Research Institute. It has been reviewed by the Office of Air Quality Planning and Standards, U. S. Environmental Protection Agency, and has been approved for publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

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-04. Mr. Dallas Safriet was the requester of the work.

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September 1995

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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 in 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 10.7, Charcoal.

This background report consists of five sections. Section 1 includes the introduction to the report. Section 2 gives a description of the charcoal manufacturing industry. It includes a characterization of the industry, a description of the different process operations, a characterization of emission sources and pollutants emitted, and a description of the technology used to control emissions resulting from these sources. Section 3 is a review of emission data collection 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 a 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 10.7, Charcoal.

2. INDUSTRY DESCRIPTION[1]

Charcoals are porous, solid, amorphous products containing 20 to 25 percent volatile matter, 70 to 75 percent fixed carbon (85 to 98 percent total carbon), 5 percent ash, low sulfur, and with a heating value of about 28 kilojoules per kilogram (kJ/kg) (12,000 British thermal units per pound [Btu/lb]). Much of the charcoal produced is converted to briquettes which are well suited for cooking and other heating applications. Smaller quantities of charcoal are used in metallurgical processes, gas or liquid treatment processes, black gun powder, arc electrodes, and inorganic and organic chemicals.

Charcoal manufacturing facilities fall under Standard Industrial Classification (SIC) code 2861, Gum and Wood Chemicals. More specifically, charcoal and charcoal briquettes fall under SIC 28611 98 (Softwood Distillation Products, Other Derivatives), and SIC 28612 57 (Other Gum and Wood Chemicals, Hardwood Distillation Products).

The six-digit Source Classification Code (SCC) for charcoal manufacturing is 3-01-006. These SCC's fall under the Chemical Manufacturing/Organic Chemicals umbrella: Charcoal/general (3-01-006-01), Charcoal/batch kiln (3-01-006-03), Charcoal/continuous furnace (3-01-006-04), Charcoal/briquetting (3-01-006-05), and Charcoal/other-not-classified (3-01-006-99).

2.1 CHARACTERIZATION OF THE INDUSTRY[2]

Statistical data on charcoal production are not available. Data are available from the Bureau of the Census for SIC Code 2861, Gum and Wood Chemicals, for softwood and hardwood distillation products, which includes charcoal and charcoal briquettes, liquid, oil, tar, and pitch products. The value of aggregated primary gum and wood chemical products shipped in 1987 was $404.2 million and $62.3 million for secondary products.

2.2 PROCESS DESCRIPTION[3-5,12]

Charcoal is the solid carbon residue following the pyrolysis (carbonization or destructive distillation) of carbonaceous raw materials. Principal raw materials are medium to dense hardwoods such as beech, birch, hard maple, hickory, and oak. Others are softwoods (primarily long leaf and slash pine), nutshells, fruit pits, coal, vegetable wastes and paper mill residues. Charcoal is used primarily as a fuel for outdoor cooking. In some instances, its manufacture may be considered as a solid waste disposal technique. Many raw materials for charcoal manufacture are wastes, as noted. Charcoal manufacture is also used in forest management for disposal of refuse.

Recovery of acetic acid and methanol byproducts was initially responsible for stimulating the charcoal industry. As synthetic production of these chemicals became commercialized, recovery of acetic acid and methanol became uneconomical.

Charcoal manufacturing kilns generally can be classified as either batch or continuous multiple hearth kilns; continuous kilns are more commonly used than are batch kilns. Batch units, such as the Missouri-type charcoal kiln, (Figure 2-1) are small, manually-loaded and -unloaded kilns producing typically 16 megagrams (Mg) (17.6 tons) of charcoal during a 3-week cycle. Continuous multiple hearth units (Figure 2-2) produce an average of 2.5 Mg per hour (Mg/hr) (2.75 tons per hour [ton/hr]) of charcoal. During the manufacturing process, the wood is heated, driving off water and highly volatile organic compounds (VOC). Wood temperature rises to approximately 275°C (527°F),

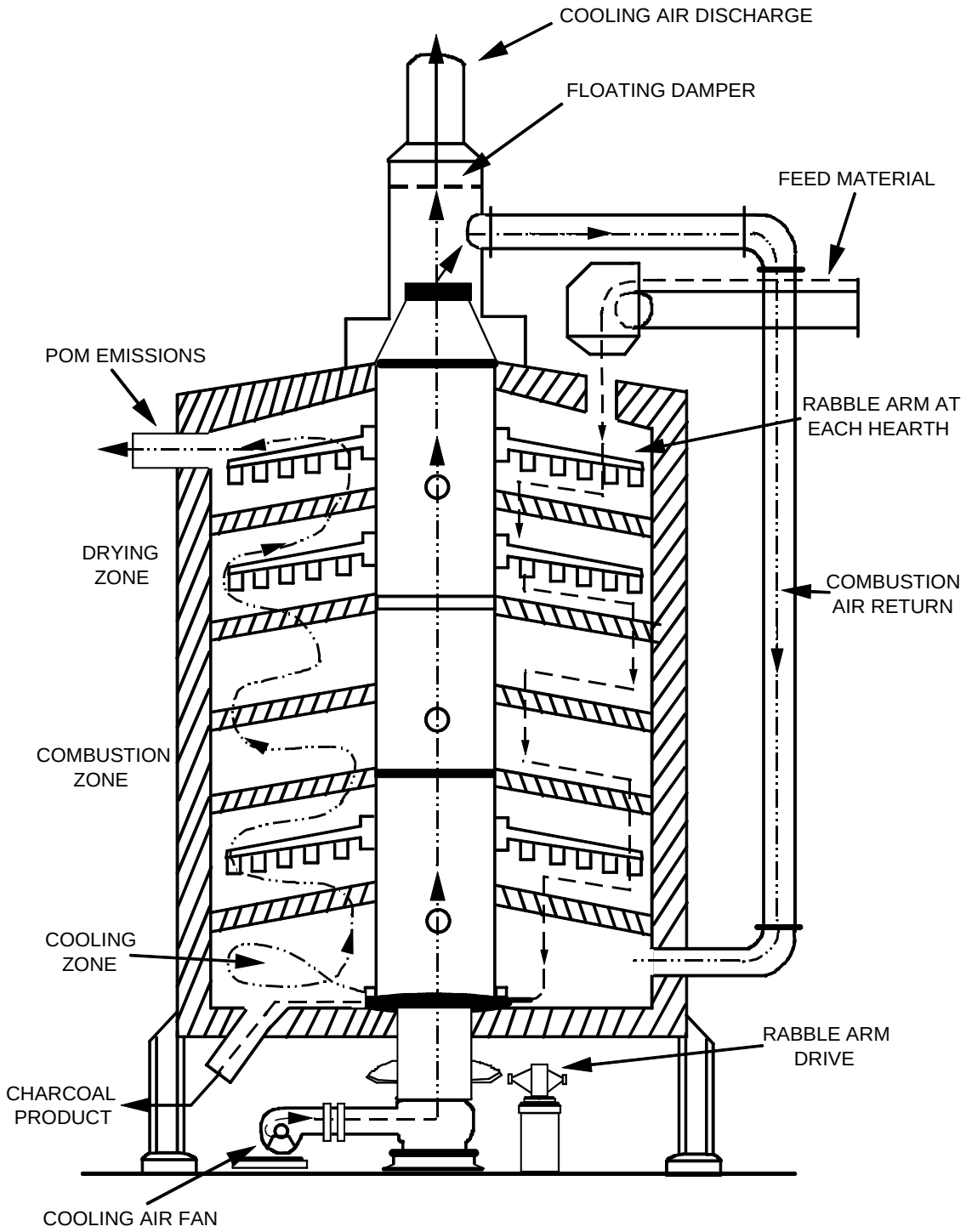

Figure 2-2. The continuous multiple hearth kiln for charcoal production.[12]
(Source Classification Code: 3-01-006-04)

and the VOC distillate yield increases. At this point, external application of heat is no longer required because the carbonization reactions become exothermic. At 350°C (660°F), exothermic pyrolysis ends, and heat is again applied to remove the less volatile tarry materials from the product charcoal.

Fabrication of briquettes from raw material may be either an integral part of a charcoal producing facility, or an independent operation, with charcoal being received as raw material. Figure 2-3 presents a flow diagram for charcoal briquette production. Raw charcoal is first crushed to pass through an approximately 3 millimeter (0.12 inch) screen aperture and then stored for briquetting. The charcoal is then mixed with a binder to form a 65 to 70 percent charcoal mixture. Typical binder solutions are 9 to 10 percent by weight solutions of cornstarch, milostarch, or wheatstarch. Sawdust or other materials may be added to obtain faster burning or higher temperatures. Briquettes are then formed in a press and dried at approximately 135°C (275°F) for 3 to 4 hours, resulting in a product with a 5 percent moisture content. This process generates a briquette of approximately 90 percent pyrolysis product.

2.3 EMISSIONS[5-12]

There are five types of products and byproducts from charcoal production operations: charcoal, noncondensible gases (carbon monoxide [CO], carbon dioxide [CO_2], methane, and ethane), pyroacids (primarily acetic acid and methanol), tars and heavy oils, and water. With the exception of charcoal, all of these materials are emitted with the kiln exhaust. Product constituents and the distribution of these constituents vary, depending on raw materials and carbonization parameters. Organics and CO are naturally combusted to CO_2 and water before leaving the retort. Because the extent of this combustion varies from plant to plant, emission levels are quite variable. Some of the specific organic pollutants that may be found in kiln emissions include ethane, methane, methanol, and polycyclic organic matter (POM). If uncombusted, tars may solidify to form particulate matter (PM) emissions, and pyroacids may form aerosol emissions.

The charcoal briquetting process is also a potential source of emissions. The crushing, screening, and handling of the dry raw charcoal may produce PM and PM-10 emissions. Briquette pressing and drying may be a source of VOC emissions, depending on the type of binder and other additives used.

2.4 CONTROL TECHNOLOGY[5-13]

Continuous production of charcoal is more amenable to emission control than batch production because emission composition and flow rate are relatively constant. Emissions from continuous multiple hearth charcoal kilns generally are controlled with afterburners. Cyclones, which commonly are used for product recovery, also reduce PM emissions from continuous kilns. Afterburning is estimated to reduce emissions of PM, CO, and VOC by at least 80 percent. Control of emissions from batch-type charcoal kilns is difficult because the process and, consequently, the emissions are cyclic. Throughout the cycle, both the emission composition and flow rate change. Batch kilns do not typically have emission control devices, but some may use afterburners.

Particulate matter emissions from briquetting operations can be controlled with centrifugal collection (65 percent control) or fabric filtration (99 percent control).

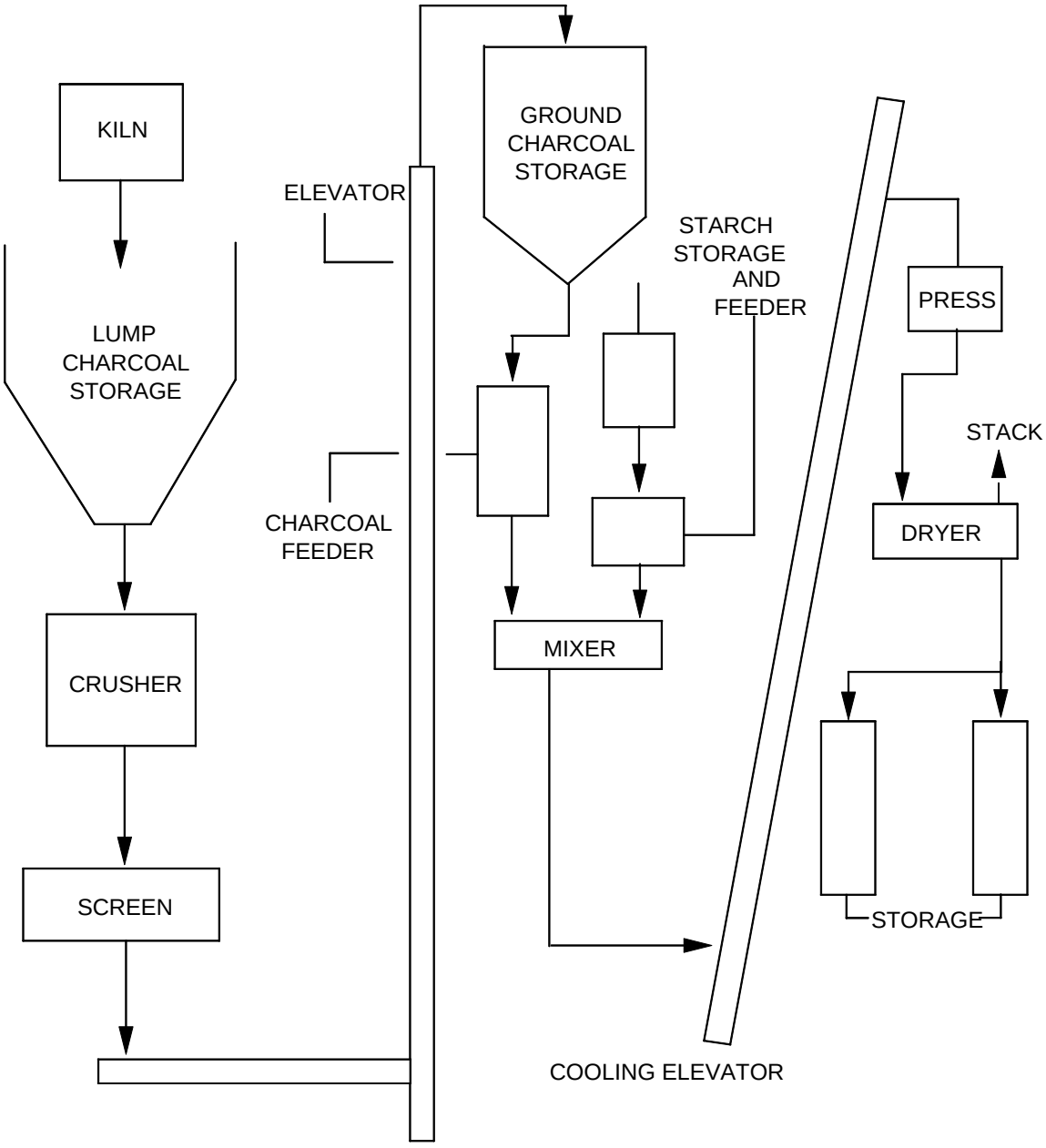

Figure 2-3. Flow diagram for charcoal briquette production.[5]
(Source Classification Code: 3-01-006-05)

REFERENCES FOR SECTION 2

1. T. H. Wegner, *et al*., Wood: Charcoal Production, in *Kirk-Othmer Encyclopedia of Chemical Technology*, Third Edition, M. Grayson, ed., Volume 24, Interscience Publishers, NY, 1984, pp. 603-611.

2. Bureau of the Census, U.S. Department of Commerce, 1987 Census of Manufacturers, Industry Series, MC87-I-28F, Industrial Organic Chemicals, Industries 2861, 2865, and 2869. U.S. Government Printing Office, Washington, D.C. March 1990.

3. *Air Pollutant Emission Factors*, APTD-0923, U. S. Environmental Protection Agency, Research Triangle Park, NC, April 1970.

4. R. N. Shreve, *Chemical Process Industries*, Third Edition, McGraw-Hill, NY, 1967.

5. C. M. Moscowitz, *Source Assessment: Charcoal Manufacturing State of the Art*, EPA-600/2-78-004z, U. S. Environmental Protection Agency, Cincinnati, OH, December 1978.

6. *Riegel's Handbook of Industrial Chemistry*, Seventh Edition, J. A. Kent, ed., Van Nostrand Reinhold Company, NY, 1974.

7. J. R. Hartwig, "Control of Emissions from Batch-Type Charcoal Kilns," *Forest Products Journal*, 21(9):49-50, April 1971.

8. W. H. Maxwell, *Stationary Source Testing of a Missouri-Type Charcoal Kiln*, EPA-907/9-76-001, U. S. Environmental Protection Agency, Kansas City, MO, August 1976.

9. R. W. Rolke, *et al*., *Afterburner Systems Study*, EPA-RZ-72-062, U. S. Environmental Protection Agency, Research Triangle Park, NC, August 1972.

10. B. F. Keeling, *Emission Testing the Missouri-Type Charcoal Kiln*, Paper 76-37.1 presented at the 69th Annual Meeting of the Air Pollution Control Association, Portland, OR, June 1976.

11. P. B. Hulman, *et al*., *Screening Study on Feasibility of Standards of Performance for Wood Charcoal Manufacturing*, EPA Contract No. 68-02-2608, Radian Corporation, Austin, TX, August 1978.

12. Radian Corporation, *Locating and Estimating Air Emissions from Sources of Polycyclic Organic Matter (POM)*, prepared by G. W. Brooks, *et al*., EPA-450/4-84-007p, U.S. Environmental Protection Agency, Research Triangle Park, NC, May 1988.

13. Written communication from J. Swiskow, Barbecue Industry Association, Naperville, IL, to D. Safriet, U. S. Environmental Protection Agency, Research Triangle Park, NC, February 11, 1994.

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 Factor and Inventory Group (EFIG) were reviewed for information on the industry, processes, and emissions. The Crosswalk/Air Toxic Emission Factor Data Base Management System (XATEF) and 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.

Numerous 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 charcoal industry. The EPA library was searched for additional test reports.

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 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 (e.g., 1-page reports were generally rejected).

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

3.2 EMISSION 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 such deviations occurred, the extent to which such alternative procedures could influence the test results was evaluated.

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. Laboratory 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 always noted.

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 of this report.

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 presents the information used to revise the AP-42 section on charcoal manufacturing. The following paragraphs (Section 4.2) describe the reports that contained emission data and other information that was used to develop the candidate emission factors for the source category. Then, emission factors on charcoal manufacturing presented in the XATEF and SPECIATE data bases also are discussed. Section 4.3 describes how the data were used to develop candidate emission factors for charcoal manufacturing. Finally, a summary of the changes to the AP-42 section is presented in Section 4.4.

4.2 REVIEW OF SPECIFIC DATA SETS

A total of nine references were located that had either emission data or other data that could be used to develop emission factors from charcoal manufacturing. Seven of the reports (References 1 through 8 in this report) were used as the basis for the emission factors presented in the previous AP-42 section on charcoal manufacturing. Most of those reports are secondary references that presented either information on annual estimated emissions or on mass balance estimates of emissions from charcoal manufacturing. The calculations used to determine the emission factors from References 1 through 8 for the previous AP-42 section are included in the background report for the previous AP-42 section (*Emission Factor Documentation for Section 5.4, Charcoal Manufacturing)*. That background report is provided in Appendix A of this report. The following paragraphs summarize the information presented in the nine references.

4.2.1 Reference 1

This document is the 1970 edition of AP-42. Although it is referenced as the source of several of the emission factors in the previous AP-42 section on charcoal manufacturing, all of the emission factors presented in the 1970 edition were developed from data presented in the other references described below. Therefore, no further discussion of this reference is warranted.

4.2.2 Reference 2

This document includes descriptions of various chemical manufacturing and related industries. Table 32.3 of the document presents data on weight percents of the various products of hardwood distillation. The distillation products that are emitted are reported to consist of 5 percent tars and oils, 2.9 percent acetic acid or equivalent, 1.9 percent methanol, and 18.3 percent gases. The gases consist of 53 percent CO_2, 27 percent CO, and 15 percent methane by volume, which corresponds on a weight basis to 12.3 percent CO_2, 4 percent CO, and 1.3 percent methane. The remaining 5 percent of the gases is not specified. However, according to Reference 3, described below, these other gases consist primarily of NO_x and formaldehyde. Based on the weight percents reported and the ratio of 1 mass unit of charcoal produced per 4 mass units of hardwood fired, the following emission factors can be estimated in units of mass emitted per mass of charcoal produced: the factor for tars and oils is 200 kilograms per megagram (kg/Mg) (400 pounds per ton [lb/ton]); the CO factor is 160 kg/Mg (320 lb/ton); for CO_2, the factor is 492 kg/Mg (984 lb/ton); the methane factor is 50 kg/Mg (100 lb/ton); and for emissions of acetic acid (or equivalent) and methanol, the factors are 116 kg/Mg (232 lb/ton) and 76 kg/Mg (152 lb/ton), respectively. To develop emission factors for the previous AP-42 section on charcoal, it was assumed

that emissions of tars and oils represented PM emissions. In addition, the factors for acetic acid and methanol were combined and presented as nonmethane VOC. This combined factor is 192 kg/Mg (384 lb/ton). With the exception of the factors for CO_2 and methanol emissions, the other factors developed from this reference were used in the calculation of the emission factors in the previous AP-42 sections on charcoal manufacturing. Based on the uncertainties in the assumptions used, these data are rated D.

4.2.3 Reference 3

This report presents a description of the charcoal manufacturing industry and the associated emissions and control technologies. The report includes a table of emission factors, most of which were taken from the 1970 version of AP-42. However, the report also presents other data that can be used to develop emission factors for PM emissions from briquetting, NO_x, ethane, and unsaturated hydrocarbons emissions from charcoal manufacturing.

For briquetting, the report presents a range of estimated emission factors for controlled PM emissions: 2.47 kg/Mg (4.94 lb/ton) and 0.42 kg/Mg (0.84 lb/ton). The control devices are not reported but the control efficiencies are reported as 65 and 99 percent, respectively. Based on these control efficiencies, the uncontrolled emission factors range from 7 kg/Mg (14 lb/ton) to 42 kg/Mg (84 lb/ton). The document also reports an average controlled PM factor of 1.25 kg/Mg (2.5 lb/ton), based on a 95 percent control efficiency. Using this average factor for controlled emissions, the factor for uncontrolled PM emissions from briquetting is estimated as 28 kg/Mg (56 lb/ton). The report provides no details on the emission sources; it is assumed that the factor represents emissions from the entire briquetting process.

Reference 3 reports the volume percent of ethane and unsaturated hydrocarbons in the charcoal kiln exhaust stream as 3.09 and 2.72 percent. Based on these percentages and the average percent of noncondensibles in the exhaust stream, the report presents emission factors of 21 kg/Mg (42 lb/ton) and 17 kg/Mg (34 lb/ton), respectively for ethane and unsaturated hydrocarbon emissions.

An estimate of the factor for NO_x emissions from charcoal kilns is presented in Reference 3 based on the assumptions that wood typically contains 0.14 percent nitrogen, all of which is converted to nitrous oxide, and 1 mass unit of charcoal is produced from 4 mass units of hardwood. The resulting emission factor is 12 kg/Mg (24 lb/ton).

The factors for briquetting and for NO_x emissions from charcoal kilns were presented in the previous AP-42 section on charcoal. In addition, to develop emission factors for the previous AP-42 section on charcoal, the sum of the factors for ethane and unsaturated hydrocarbons, which is 38 kg/Mg (76 lb/ton), was assumed to represent nonmethane VOC. However, because ethane is not classified as a VOC, the factor for ethane is presented separately in this revision to AP-42. Based on the uncertainties in the assumptions used to estimate the emission factors presented in this reference, the data for all factors are rated D.

4.2.4 Reference 4

This journal article reports data on the distillation of 1.82 Mg (2 tons) of wood to make 0.44 Mg (0.48 tons) of charcoal. It appears that the emission data are the results of a mass balance rather than of an emission test. The emission stream from this burn consisted of 90.9 kg (200 lb) of tar, 86.4 kg (190 lb) of pyroacids, 238 kg (523 lb) of CO_2, 78.2 kg (172 lb) of CO, 25 kg (55 lb) of methane, and 13.6 kg

(30 lb) of ethane. The resulting emission factors for these compounds are 208 kg/Mg (416 lb/ton) for tar, 198 kg/Mg (396 lb/ton) for pyroacids, 545 kg/Mg (1,090 lb/ton) for CO_2, 179 kg/Mg (358 lb/ton) for CO, 57 kg/Mg (114 lb/ton) for methane, and 31 kg/Mg (62 lb/ton) for ethane. To develop factors for the previous AP-42 section, the factor for tar was assumed to represent PM emissions, and the factors for pyroacids and ethane were combined to yield a factor of 229 kg/Mg (458 lb/ton) for nonmethane VOC. For this revision to AP-42, the factor for ethane is reported separately because ethane is not classified as a VOC. The factors for methane and CO also were incorporated into the factors presented in the previous AP-42 section for charcoal; the factor for CO_2 was not used previously in AP-42. These data are assigned a rating of D.

4.2.5 Reference 5

This report presents the results of an emission test conducted on a Missouri-type charcoal kiln. Emissions from the kiln were sampled for total PM and polycyclic organic matter (POM). The organic fraction of the total PM sample was quantified, and concentrations of CO and CO_2 in the exhaust stream also were measured.

The kiln has a total of eight stacks, which were sampled during eight runs periodically over the 7-day burn cycle. Total PM emissions were measured using a modified Method 5 sampling train. The modification consisted of a cyclone mounted above a flask, which collected excess moisture from the gas stream prior to its reaching the sampling train filter. The flask contents later were combined with the impinger contents for analysis. An ether-chloroform extraction was performed on both the front half and back half samples of the train to quantify the organic fraction. For the PM test, seven runs were conducted. The first run was performed during the 3-hour startup of the kiln, before the kiln door was closed and sealed. The probe was placed in the plume originating from the kiln opening, which was assumed to be equivalent to a nominal 3 meter (10 foot) diameter stack. Subsequent samples were taken from one of the eight stacks on the kiln. Because the stacks were made of clay pipe, ports could not be cut into them. Therefore, the probe was inserted into the top of the stacks for taking measurements. Test runs lasted from 30 minutes to 4 hours. The POM train was not used to sample emissions during the kiln startup period.

The report presents emission factors for total PM based on three methods of calculation. In the previous versions of AP-42, the resulting emission factors for each calculation method were treated as separate measurements. However, the third method appears to be the most representative. In this method, emissions from the startup and shutdown periods are treated separately, and the remaining 5 runs are used to estimate the emissions during five 27.5-hour periods. Total emissions from the kiln cycle are calculated as the sum of the startup, shutdown, and five 27.5-hour periods. However, the estimated flowrate for the startup period does not appear to be reasonable; using the estimated flowrate, the CO and CO_2 emissions during the 3-hour startup period is approximately equal to the total emissions during the subsequent 165 hours of the burn cycle. Therefore, for the purposes of developing emission factors for the data, the flowrate during the startup period was assumed to be equal to the flowrate during the following run (Run 3). This assumption results in a total PM factor of 62 kg/Mg (124 lb/ton), an organic PM factor of 46 kg/Mg (92 lb/ton), a factor of 190 kg/Mg (380 lb/ton) for CO, 870 kg/Mg (1,740 lb/ton) for CO_2, and 0.0047 kg/Mg (0.0095 lb/ton) for POM. The data on emissions of organic PM, CO, CO_2, and POM were not used to develop emission factors in previous versions of AP-42. Because of the sampling problems and modifications described above, the emission data are rated D.

4.2.6 Reference 6

This document consists of a report on the design, performance, costs, and potential applications for afterburners to control emissions. The report includes a table of emission factors for charcoal manufacturing. The data in that table were used in previous AP-42 sections on charcoal manufacturing to calculate emission factors for emissions of PM, nonmethane VOC, and methane. The data are referenced to the 1971 edition of AP-42. In fact, the each of the factors is equal to the corresponding factor developed from Reference 2 multiplied by 0.88. The reason for this conversion is unclear, but, in any case, the data are redundant with Reference 2 and were not considered further in this revision to AP-42.

4.2.7 Reference 7

This reference consists of a conference paper that discusses the results of the emission test documented in Reference 5. The paper reports an average emission rate of 1.92 kg/hr (4.23 lb/hr) over the entire 21-day cycle (7 days for burning and 14 days for cooling). This rate results in an emission factor of 59 kg/Mg (118 lb/ton), which differs slightly from the emission factor presented in Reference 5 for the same emission test. The reason for the discrepancy is unclear. Because these results are redundant with Reference 5, they were not considered further in this revision to AP-42.

4.2.8 Reference 8

This reference presents the results of a screening study to determine the feasibility of new source performance standards for charcoal manufacturing. The report presents material balance data that is referenced back to Reference 4 described above. Therefore, these results also are redundant (with Reference 4) and were not considered further in this revision to AP-42.

4.2.9 Reference 9

The EPA sponsored a test of the Kingsford Charcoal Plant in Burnside, Kentucky, with the objective of collecting background information on charcoal kiln emissions to provide the basis for a decision on developing new source performance standards.

Carbon monoxide and VOC concentrations were determined by continuous monitoring instrumentation in the exhaust duct leading from charcoal kiln No. 8 to an afterburner control device. Samples were taken before the exhaust stream reached the control device in order to characterize uncontrolled emissions during the burn cycle of charcoal production. Volatile organic compound concentrations were measured using a Beckman 402 Hydrocarbon Analyzer. The analysis is based on flame ionization. Carbon monoxide concentrations were measured using a Beckman 864 Nondispersive Infrared Analyzer. Exhaust gas analysis for CO_2, O_2, excess air, and dry molecular weight was performed using EPA Method 3. Moisture levels were determined by EPA Method 4. Because of high moisture and the presence of tar-like particulate in the exhaust stream, a condenser was installed in the sample line for the VOC train. The condenser was operated intermittently throughout the test.

Figure 1 of the reference contains flow rates (ACFM) and temperature (°F) measured at different times during the 3-day period May 3 through 5, 1980. Based on these data, average flow rates and temperatures were computed for each day. The report also contains moisture content (in the exhaust gases) data for this 3-day period. Average moisture content for each day was computed. Finally, the CO and CO_2 content (on a dry basis) are reported for each of the three days in Table 1 of the reference.

Using the average flow rate, temperature, moisture content, and the levels of CO and CO_2, mass emission rates were computed for both CO and CO_2 each day. A sample calculation for the estimation of CO emission rate for May 3, 1980 is given below:

$$0.035 \frac{ft^3 \text{ CO}}{ft^3 \text{ dry air}} \text{ X } 2{,}630 \frac{ft^3}{min} \text{ X } \left(1 - \frac{37}{100}\right) \text{ X } \frac{\text{lb mole}}{387 \text{ ft}^3 \text{ @ } 530°\text{R}} \text{ X } \frac{530}{(460 + 160)}$$

$$\text{X } \quad 60 \frac{min}{hr} \text{ X } 24 \frac{hr}{d} \text{ X } 28 \frac{\text{lb CO}}{\text{lb mole}} = 5{,}165 \text{ lb/d}$$

In this manner, the average CO and CO_2 emission rates were computed for each day. The daily emission rates of each pollutant were added together to obtain the emissions during the batch process duration.

The actual process rate for kiln No. 8 was not provided in the test report. However, a process capacity range was given. The midpoint of the range was used for calculating the CO and CO_2 emission factors. Because the calculated emission factors are based on an average capacity rather than on an actual process rate, these emission data are assigned a data rating of D; the emission factors developed from these data are rated E.

As mentioned previously, the condenser installed in the VOC sample line was operated intermittently during the test. The data indicate that the condenser had a significant impact on VOC concentrations in the exhaust stream; when the condenser was activated, VOC concentrations dropped to as low as 5 percent of the concentrations immediately prior to the condenser being activated. For this reason, the VOC data cannot be considered representative of VOC emissions, and an emission factor was not developed from the data.

4.2.10 Review of XATEF and SPECIATE Data Base Emission Factors

The XATEF data base includes emission factors for acetic acid, methanol, and polycyclic organic matter (POM) from charcoal manufacturing. The controlled and uncontrolled emission factors for acetic acid and methanol are based on a source assessment report (C. M. Moscowitz, *Source Assessment: Charcoal Manufacturing State of the Art*, EPA-600/2-78-004z, U. S. Environmental Protection Agency, Cincinnati, OH, December 1978), which has already been cited as a source in the existing AP-42 section on charcoal (see Reference 3). Consequently, these emission factors are incorporated in the existing AP-42 section on charcoal.

The emission factor for POM from a general charcoal manufacturing process is based on a draft report prepared for the Ontario Ministry of the Environment (ORTECH Corporation, *MOE Toxic Chemical Emissions Inventory for Ontario and Eastern North America*, prepared by N. D. Johnson and M. T. Shultz for the Ontario Ministry of the Environment, Air Resources Branch, Rexdale, Ontario, Draft Report No. P89-50-5429/OG, March 15, 1990). This report could not be obtained within the timeframe for generating this report. Because the primary reference has not been obtained, these emission factors were not incorporated into this version of AP-42 Section 10.7.

The uncontrolled emission factor for POM from a Missouri-type batch kiln is based on a locating and estimating document (Radian Corporation, *Locating and Estimating Air Emissions from Sources of Polycyclic Organic Matter (POM)*, prepared by G. W. Brooks, et al., EPA-450/4-84-007p, U. S. Environmental Protection Agency, Research Triangle Park, NC, May 1988). This document gives an emission factor based solely on a source assessment report, which has been referenced for other emission

factors previously incorporated in the AP-42 section on charcoal (see Reference 3). According to the report, the emission factors are based on a review of the literature, and most of the estimates found in the literature were derived from material-balance calculations based on laboratory wood pyrolysis studies. The limited sampling data that were available were of a questionable nature because nonstandard sampling techniques were used. Therefore, the emission factor for POM from charcoal manufacturing was not incorporated into AP-42 Section 10.7.

The SPECIATE data base includes no emission factors for speciated VOC emissions from charcoal production.

The SPECIATE data base includes emission factors for speciated PM emissions from charcoal production. These emission factors are based on a report written for the Oregon Department of Environmental Quality (R. T. DeCesar, and J. A. Cooper, *Medford Aerosol Characterization Study, Final Report*, prepared for the State of Oregon, Department of Environmental Quality, February 1981). According to the report, charcoal manufacturing was targeted for source sampling during the project. However, the report goes on to say that "it was not possible to obtain such a sample because of the high temperatures associated with the charcoal plant stack . . . ." Hence, this report has no emission factors for charcoal manufacture. Because no original data were found to corroborate the emission factors found in SPECIATE for speciated PM from charcoal manufacture, they were not incorporated into AP-42 Section 10.7.

4.3 DEVELOPMENT OF CANDIDATE EMISSION FACTORS

Table 4-1 summarizes the emission data on charcoal manufacturing. Emission factors are included for one emission source: charcoal kilns. For charcoal kilns, two of the reports (References 5 and 9) document emission tests conducted on Missouri-type batch kilns; one of the reports (Reference 4) presents the results of an emission test conducted on a Missouri-type kiln; and References 2 and 3 present mass balance data for wood pyrolysis, irrespective of kiln type. Table 4-2 presents the "average" emission factors for both batch-type and continuous kilns, based on the factors presented in Table 4-1. The average factors for batch kilns are based on all of the data, and the average factors for continuous kilns are based on only the mass balance data from References 2 and 3. As Table 4-2 indicates, the factors for both types of kilns are similar. In view of the quality of the data, it is reasonable to assume that the data indicate no significant differences in the factors for batch and continuous kilns. Therefore, the factors developed from all data are assumed to be applicable to both batch and continuous multiple hearth charcoal kilns.

TABLE 4-2. COMPARISON OF AVERAGE EMISSION FACTORS FOR CHARCOAL KILNS[a]

Pollutant	Emission factor					
	Batch kilns			Continuous kilms		
	kg/Mg	lb/ton	References	kg/Mg	lb/ton	References
Total PM	160	310	2,4,5	200	400	2
Organic PM	46	92	5	ND	ND	
CO	140	290	2,4,5,9	160	320	2
NO_x	12	24	3	12	24	3
CO2	560	1,100	2,4,5,9	492	984	2
VOC	140	270	2,3,4	100	210	2,3
Methane	54	110	2,4	50	100	2
Ethane	26	52	3,4	21	42	3
POM	0.0047	0.0095	5	ND	ND	
Methanol	76	150	2	76	152	2

TABLE 4-1. SUMMARY OF EMISSION DATA FOR CHARCOAL MANUFACTURING[a]

Process/source	Kiln type	Pollutant	Data rating	Emission factor		
				kg/Mg	lb/ton	Reference
Charcoal kiln	Batch/continuous	total PM[b]	D	200	400	2
Charcoal kiln	Batch/continuous	CO_2	D	492	984	2
Charcoal kiln	Batch/continuous	CO	D	160	320	2
Charcoal kiln	Batch/continuous	methane	D	50	100	2
Charcoal kiln	Batch/continuous	methanol	D	76	152	2
Charcoal kiln	Batch/continuous	acetic acid (or equivalent)	D	116	232	2
Charcoal kiln	Batch/continuous	VOC[d]	D	192	384	2
Briquetting	NA	total PM	D	28	56	3
Charcoal kiln	Batch/continuous	ethane	D	21	42	3
Charcoal kiln	Batch/continuous	VOC[e]	D	17	34	3
Charcoal kiln	Batch/continuous	NO_x	D	12	24	3
Charcoal kiln	Batch	total PM[b]	D	208	416	4
Charcoal kiln	Batch	ethane	D	31	62	4
Charcoal kiln	Batch	VOC[c]	D	198	396	4
Charcoal kiln	Batch	methane	D	57	114	4
Charcoal kiln	Batch	CO	D	179	358	4
Charcoal kiln	Batch	CO_2	D	545	1,090	4
Charcoal kiln	Batch	total PM	D	62	124	5
Charcoal kiln	Batch	organic PM	D	46	92	5
Charcoal kiln	Batch	CO	D	190	380	5
Charcoal kiln	Batch	CO_2	D	870	1,740	5
Charcoal kiln	Batch	POM	D	0.0047	0.0095	5
Charcoal kiln	Batch	CO	D	48	96	9
Charcoal kiln	Batch	CO_2	D	350	700	9

[a]Factors in units of kg/Mg and lb/ton of product. NA = not applicable. NR = not rated.
[b]Based on estimated content of tars and oils in exhaust stream.
[c]Sum of factors for methanol and acetic acid.
[d]Based on estimated emissions of unsaturated hydrocarbons.
[e]Based on estimated emissions of pyroacids.

Table 4-3 summarizes the candidate emission factors for charcoal manufacturing. The factors for kilns presented in the table are in units of mass of pollutant emitted per mass of charcoal produced. The factor for briquetting indicated in Table 4-3 is based on the information presented in Reference 3, which was the only reference that presented rated data on this source. Reference 3 does not provide details on the basis for the briquetting. Therefore, it is assumed that the data represents the entire briquetting process. The units of this factor are assumed to be mass of pollutant emitted per mass of briquette.

TABLE 4-3. SUMMARY OF CANDIDATE EMISSION FACTORS FOR CHARCOAL MANUFACTURING[a]

Process/source	Pollutant	No. of data sets	Emission factor						Rating	References
			kg/Mg			lb/ton				
			Minimum	Maximum	Average	Minimum	Maximum	Average		
Charcoal kiln	total PM[b]	3	62	208	160	124	416	310	E	2,4,5
Charcoal kiln	CO	4	48	190	140	96	380	290	E	2,4,5,9
Charcoal kiln	NOx	1	NA	NA	12	NA	NA	24	E	3
Charcoal kiln	CO_2	4	350	870	560	700	1,700	1,100	E	2,4,5,9
Charcoal kiln	VOC	3	17	198	140	34	396	270	E	2,3,4
Charcoal kiln	methane	2	50	57	54	100	114	110	E	2,4
Charcoal kiln	ethane	2	21	31	26	42	62	52	E	3,4
Charcoal kiln	methanol	1	NA	NA	76	NA	NA	150	E	2
Charcoal kiln	POM	1	NA	NA	0.0047	NA	NA	0.0095	E	5
Briquetting[d]	total PM	1	NA	NA	28	NA	NA	56	E	3

[a]Factor units are kg/Mg and lb/ton of product (charcoal or briquette). All factors are for uncontrolled emissions.
[b]Includes condensibles and consists primarily of tars and oils; approximately 74 percent consists of organic material.
[c]Consists primarily of methanol, acetic acid, formaldehyde, pyroacids, and unsaturated hydrocarbons.
[d]For entire briquetting process.

The emission factors presented in Table 4-3 for charcoal kilns are based on arithmetic averages of all available data. A separate emission factor for organic PM emissions is not presented because the total PM emission estimates from References 2 and 4 are based on the assumption that all PM emissions consist of organic compounds. This assumption is inconsistent with the data presented in Reference 5. Because the candidate emission factors presented in Table 4-3 all are based on D-rated data, they are rated E.

4.4 SUMMARY OF CHANGES TO AP-42 SECTION

4.4.1 Section Narrative

The process description for briquetting manufacturing was expanded to provide more details on that process. A process flow diagram for briquetting also was added to the section. In addition, the discussion of emissions and controls was expanded to provide more information on organic emissions and emission control systems. Finally, the revised AP-42 section clarifies that the factors presented are for charcoal kilns (applicable to batch or continuous multiple hearth kilns) and the entire briquetting process; the previous AP-42 section presented factors as representative of emissions of "charcoal manufacturing" and "briquetting" without further explanation.

4.4.2 Emission Factors

The factors for NO_x emissions from charcoal kilns and for total PM emissions from briquetting are unchanged from the previous AP-42 section. The other factors differ from the factors presented in the previous version in AP-42. Table 4-4 summarizes the changes in factors. As discussed in Section 4.2 of this report, the references used to develop emission factors for the revised AP-42 section are largely the same reports as used previously for AP-42. However, several of the references included redundant data; by eliminating these redundancies, the emission factors changed. In addition, the data from one new emission test report were used, and some of the previously unused data from the old references were used to develop factors. As a result, new factors were added for emissions of CO_2, methanol, and POM from charcoal kilns.

TABLE 4-4. SUMMARY OF CHANGES TO EMISSION FACTORS FOR CHARCOAL MANUFACTURING

Source	Pollutant	Emission factor			
		Previous		Revised	
		kg/Mg	lb/ton	kg/Mg	lb/ton
Kiln	Total PM	133	266	160	310
Kiln	CO	172	344	140	290
Kiln	NO_x	No change			
Kiln	VOC	157	314	140	270
Kiln	Methane	52	104	54	110
Kiln	Ethane	No factor[a]		26	52
Kiln	CO_2	No factor		560	1,100
Kiln	Methanol	No factor[a]		76	150
Kiln	POM	No factor[b]		0.0047	0.0095
Briquetting	Total PM	No change			

[a]Previously incorporated into the factor for nonmethane VOC, but was not reported separately.
[b]Previously included in footnote to emission factor table as 4.0 mg/kg, which is equivalent to 0.0040 kg/Mg (0.0080 not reported separately in emission factor table.

All factors presented in the previous AP-42 section on charcoal were assigned a rating of C. In the revised section, the factors are rated E to better reflect the quality of the data.

REFERENCES FOR SECTION 4

1. *Air Pollutant Emission Factors*, APTD-0923, U. S. Environmental Protection Agency, Research Triangle Park, NC, April 1970.

2. R. N. Shreve, *Chemical Process Industries*, Third Edition, McGraw-Hill, NY, 1967.

3. C. M. Moscowitz, *Source Assessment: Charcoal Manufacturing State of the Art*, EPA-600/2-78-004z, U. S. Environmental Protection Agency, Cincinnati, OH, December 1978.

4. J. R. Hartwig, "Control of Emissions from Batch-type Charcoal Kilns", *Forest Products Journal*, *21*(9):49-50, April 1971.

5. W. H. Maxwell, *Stationary Source Testing of a Missouri-type Charcoal Kiln*, EPA-907/9-76-001, U. S. Environmental Protection Agency, Kansas City, MO, August 1976.

6. R. W. Rolke, *et al.*, *Afterburner Systems Study*, EPA-RZ-72-062, U. S. Environmental Protection Agency, Research Triangle Park, NC, August 1972.

7. B. F. Keeling, *Emission Testing the Missouri-type Charcoal Kiln*, Paper 76-37.1, presented at the 69th Annual Meeting of the Air Pollution Control Association, Portland, OR, June 1976.

8. P. B. Hulman, *et al.*, *Screening Study on Feasibility of Standards of Performance for Wood Charcoal Manufacturing*, EPA Contract No. 68-02-2608, Radian Corporation, Austin, TX, August 1978.

9. *Emission Test Report*, Kingsford Charcoal, Burnside, Kentucky, prepared by Monsanto Research Corporation for U. S. Environmental Protection Agency, Research Triangle Park, NC, August 1980.