MIDWEST RESEARCH INSTITUTE

MRI REPORT

CONTROL TECHNOLOGY FOR SOURCES OF PM_{10}

DRAFT REPORT

EPA Contract No. 68-02-3891, Work Assignment 4
MRI Project No. 8281-L(4)

September 1985

For

U.S. Environmental Protection Agency
Office of Air Quality Planning and Standards
Control Programs Development Division
Research Triangle Park, North Carolina 27711

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CONTROL TECHNOLOGY FOR SOURCES OF PM_{10}

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PREFACE

This report was prepared by Midwest Research Institute (MRI) for the U.S. Environmental Protection Agency's Control Programs Development Division as part of Work Assignment 4 of Contract No. 68-02-3891. Mr. Kenneth Woodard was the EPA project officer. The work was performed in MRI's Air Quality Assessment Section (Dr. Chatten Cowherd, Head). The report was prepared by Mr. John Kinsey (Principal Investigator), Mr. Steve Schliesser, and Mr. Phillip Englehart.

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MIDWEST RESEARCH INSTITUTE

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SECTION 1.0

INTRODUCTION

The U.S. Environmental Protection Agency (EPA) has proposed national ambient air quality standards (NAAQS) for particulate matter based on particles of a size equal to or smaller than 10 microns (μm) in aerodynamic diameter (PM_{10}) for the primary standard, and total suspended particulate (TSP) for the secondary standard. TSP is defined as particulate matter which is of a size approximately equal to or smaller than 30 microns (μm) in aerodynamic diameter. Revision of the standards will make it necessary that State Implementation Plans (SIPs) be reviewed to determine changes that may be required to attain and maintain the new standards. Included in the SIP review process will be an analysis of the existing control strategy to determine whether additional control technology will be required for existing sources of PM_{10} to attain and maintain the new NAAQS.

In order to develop appropriate control strategies for sources of PM_{10}, a step-wise procedure must be followed. This procedure includes: (1) the determination of uncontrolled PM_{10} emission rates; (2) the identification of available control options; (3) the determination of the emissions reduction achieved by various control options; and (4) the estimation of control costs and cost-effectiveness for each option. This document will provide guidance on each step in the above procedure. It will also present various approaches for determining compliance with applicable PM_{10} emission standards (when promulgated), based on either a determination of on-site performance (e.g., source tests, opacity) or other procedures such as recordkeeping. First, appropriate definitions and reference documents will be presented as an introduction to the main discussion provided in the following sections.

1.1 DEFINITIONS

Ducted emission sources are those sources of particulate matter which vent emissions to the atmosphere through a stack, vent, or pipe designed to direct or control their flow. Point sources are usually controlled by means of one or more types of traditional industrial gas cleaning equipment such as electrostatic precipitators, baghouses, and wet scrubbers.

Fugitive emissions refer to those pollutants that: (1) enter the atmosphere without first passing through a stack or duct designed to direct or control their flow; or (2) leak from ducting systems. Sources of fugitive particulate emissions may be separated into two broad categories: process sources and open dust sources.

Process sources of fugitive emissions are those associated with industrial operations that alter the chemical or physical characteristics of a feed material. Examples are emissions from charging and tapping of metallurgical furnaces and emissions from crushing of mineral aggregates. Such emissions normally occur within buildings and, unless captured, are discharged to the atmosphere through forced or natural draft ventilation systems. However, a process source can also be located in the open atmosphere (e.g., scrap metal cutting). The most significant process sources of fugitive particulate emissions are listed by industry in Table 1-1.

Open dust sources are those which entail generation of fugitive emissions by the forces of wind or machinery acting on exposed materials. Open dust sources include industrial operations associated with the open transport, storage, and transfer of raw, intermediate, and waste aggregate materials and nonindustrial sources such as unpaved roads and parking lots, paved streets and highways, heavy construction activities, exposed areas and agricultural tilling. Generic categories of open dust sources are listed in Table 1-2.

TABLE 1-1. CATEGORIES OF PROCESS FUGITIVE SOURCES

Industry	Process source
Iron and Steel Plants	Coal Crushing/Screening Coke Ovens Coke Oven Pushing Sinter Machine Windbox Sinter Machine Discharge Sinter Cooler Blast Furnace Charging Blast Furnace Tapping Slag Crushing/Screening Molten Iron Transfer BOF Charging/Tapping/Leaks Open Hearth Charging/Tapping/Leaks EAF Charging/Tapping/Leaks Ingot Pouring Continuous Casting Scarfing
Ferrous Foundries	Furnace Charging/Tapping Ductile Iron Inoculation (w/wo tundish cover) Pouring of Molten Metal Casting Shakeout Cooling/Cleaning/Finishing of Castings Core Sand and Binder Mixing
Primary Aluminum Production	Grinding/Screening/Mixing/Paste Production Anode Baking Electrolytic Reduction Cell Refining and Casting
Primary Copper Smelters	Roaster Charging Roaster Leaks Furnace Charging/Tapping/Leaks
Primary Copper Smelters	Slag Tapping/Handling Converter Charging/Leaks Blister Copper Tapping/Transfer Copper Tapping/Casting

(continued)

TABLE 1-1. (continued)

Industry	Process source
Primary Lead Smelters	Raw Material Mixing/Pelletizing Sinter Machine Leaks Sinter Return Handling Sinter Machine Discharge/Screens Sinter Crushing Blast Furnace Charging/Tapping Lead and Slag Pouring Slag Cooling Slag Granulator Zinc Fuming Furnace Vents Dross Kettle Silver Retort Building Lead Casting
Primary Zinc Production	Sinter Machine Windbox Discharge Sinter Machine Discharge/Screens Coke-Sinter Mixer Furnace Tapping Zinc Casting
Secondary Aluminum Smelters	Sweating Furnace Smelting Furnace Charging/Tapping Fluxing Dross Handling and Cooling
Secondary Lead Smelters	Scrap Burning Sweating Furnace Charging/Tapping Reverb Furnace Charging/Tapping Blast Furnace Charging/Tapping Pot Furnace Charging/Tapping Tapping of Holding Pot Casting
Secondary Zinc Production	Sweating Furnace Charging/Tapping Hot Metal Transfer Melting Furnace Charging/Tapping Distillation Retort Charging/Tapping Distillation Furnace Charging/Tapping Casting

(continued)

TABLE 1-1. (concluded)

Industry	Process source
Secondary Copper, Brass/ Bronze Production	Sweating Furnace Charging/Tapping Dryer Charging/Tapping Melting Furnace Charging Casting
Ferroalloy Production	Raw Materials Crushing/ Screening Furnace Charging Furnace Tapping Casting
Cement Manufacturing	Limestone/Gypsum Crushing and Screening Coal Grinding
Lime Manufacturing	Limestone Crushing/Screening Lime Screening/Conveying
Rock Products	Blasting Primary Crushing/Screening Secondary Crushing/Screening Tertiary Crushing Screening
Asphalt Concrete Plants	Aggregate Crushing/Screening Pugmill/Dryer Drum
Coal-Fired Power Plants	Coal Pulverizing/Screening
Grain Storage and Processing	Grain Cleaning Grain Drying
Wood Products Industry	Log Debarking/Sawing Veneer Drying Plywood Cutting Plywood Sanding
Mining	Blasting Crushing/Screening

TABLE 1-2. GENERIC CATEGORIES OF OPEN DUST SOURCES

1. Unpaved Travel Surfaces

   - Roads
   - Parking lots and staging areas
   - Storage piles

2. Paved Travel Surfaces

   - Streets and highways
   - Parking lots and staging areas

3. Exposed Areas (wind erosion)

   - Storage piles
   - Bare (unvegetated) ground areas

4. Materials Handling

   - Batch drop (dumping)
   - Continuous drop (conveyor transfer, stacking)
   - Pushing (dozing, grading, scraping)
   - Tilling

The partially enclosed storage and transfer of materials to or from a process operation do not fit well into either of the two categories of fugitive particulate emissions defined above. Examples are partially enclosed conveyor transfer stations and front-end loaders operating within buildings. Nonetheless, partially enclosed materials handling operations should be classified as open sources.

The various open dust sources listed in Table 1-2 can be found either in an industrial facility or in the public sector. The mechanisms of dust formation and thus the type of controls which can be applied in either case are essentially the same. However, both the suitability and cost-effectiveness associated with a specific control measure can change significantly when applied in an industrial setting as compared to the same control used for public sector sources. Therefore, the control strategies developed by public agencies often differ from those employed by industrial concerns.

A number of public sector sources are perceived as single sources when in actuality they are a series of different dust generating operations confined to the same locality. Examples of this type of source include construction and demolition activities, both of which involve dust generation by various materials handling operations as well as vehicular traffic. Table 1-3 lists the specific sources associated with construction and demolition activities using the same general notation indicated in Tables 1-1 and 1-2 above.

TABLE 1-3. OPEN DUST SOURCES ASSOCIATED WITH CONSTRUCTION AND DEMOLITION

1. Construction Sites
   - Vehicular traffic on unpaved surfaces
   - Storage piles
   - Mud/dirt carryout onto paved travel surfaces
   - Exposed areas
   - Batch drop operations
   - Pushing (earth moving)
   - Blasting
2. Demolition Sites
   - Vehicular traffic on unpaved surfaces
   - Storage piles
   - Mud/dirt carryout onto paved travel surfaces
   - Exposed areas
   - Batch drop operations
   - Pushing (dozer operation)
   - Blasting

One final public sector source worthy of note is agricultural tilling. Tilling involves those operations associated with soil preparation, maintenance, and crop harvesting activities. The emissions from these operations are generally significant but are usually not controlled except by operational (e.g., tilling) modifications. Since add-on controls are not generally applicable to agricultural tilling, such will not be covered in detail in this document.

Finally, control cost-effectiveness is defined in this document as the dollars expended per unit mass of emissions reduced (i.e., \$/Mg). Cost effectiveness is a direct function of the initial capital investments as well as the annualized costs of labor, operation, and maintenance. This will be discussed in detail in Section 4.

1.2 REFERENCE DOCUMENTS

In order to develop appropriate control strategies for PM_{10}, a number of basic reference documents must be available to the person conducting the analysis. These documents are listed in Table 1-4 in the order that they appear in this handbook. It is strongly recommended that the user obtain a copy of each of these reference documents prior to proceeding with any type of analysis for the control of PM_{10}. All of the documents listed are available either through the National Technical Information Service in Springfield, Virginia, or from the EPA's Office of Air Quality Planning and Standards in Durham, North Carolina.

1.3 ORGANIZATION OF HANDBOOK

The remainder of this document is organized as follows:

- Section 2 - Quantification of Uncontrolled Emissions
- Section 3 - Control Alternatives for PM_{10}
- Section 4 - Estimation of Control Costs/Cost Effectiveness
- Section 5 - Methods of Compliance Determination

TABLE 1-4. LIST OF STANDARD REFERENCE DOCUMENTS

U.S. Environmental Protection Agency. Compilation of Air Pollutant Emission Factors. ~~3rd~~ Edition ~~(Supplements 1-15)~~, AP-42, Office of Air Quality Planning and Standards, Research Triangle Park, NC, ~~January 1984.~~

U.S. Environmental Protection Agency. Control Techniques for Particulate Emissions from Stationary Sources - Volumes 1 and 2. EPA-450/3-81-005, Emission Standards and Engineering Division, Research Triangle Park, NC, September 1982.

Cowherd, C., et al. Identification, Assessment, and Control of Fugitive Particulate Emissions. Final Report, EPA Contract No. 68-02-3922, Midwest Research Institute, Kansas City, MO, April 1985.

Neveril, R. B. Capital and Operating Costs of Selected Air Pollution Control Systems. EPA-450/5-80-002, U.S. Environmental Protection Agency, Research Triangle Park, NC, 1980.

SECTION 2.0

QUANTIFICATION OF UNCONTROLLED EMISSIONS

In developing an uncontrolled emissions inventory, the large number of individual sources and the diversity of source types make impractical the field measurement of emissions at each point of release. Usually, the only feasible method of determining pollutant emissions is to estimate the typical emissions for each of the source types.

In general, calculation of the estimated emission rate for a given source requires data on production rate or source extent, the uncontrolled emission factor and control efficiency. The mathematical expression for this calculation is as follows:

$$R = Me\,(1 - c) \qquad (2\text{-}1)$$

where: R = mass emission rate

M = production rate or source extent

e = uncontrolled emission factor (i.e., rate of uncontrolled emissions per unit of production or source extent)

c = fractional efficiency of control

The emission factor is an estimate of the rate at which a pollutant is released to the atmosphere from an uncontrolled source divided by the level of production or source activity.

The document Compilation of Air Pollutant Emission Factors (AP-42), published by the EPA since 1972, is a compilation of emission factor values for the most significant source categories.[1] As more information about sources and control of emissions has become available, supplements to AP-42 (1-15) have been published to include new emission source categories and update existing source categories. Because the nation-wide effort to control industrial sources of pollution initially focused on discharge from point sources, most of the factors compiled in AP-42 apply to point source particulate emissions. However, with the increasing recognition of the importance of fugitive particulate emissions, EPA has undertaken extensive field testing to develop emission factors for fugitive sources.

The following sections briefly discuss the various emission factors available to estimate the uncontrolled emissions from both point and fugitive sources of PM_{10}.

2.1 DUCTED SOURCE EMISSION FACTORS

As stated above, total particulate emission factors have been published in AP-42 for ducted sources representing a multiplicity of industries and processes. These factors are derived from data collected using standard source sampling techniques such as EPA Method 5. The emission factors are routinely expressed in terms of kilograms (kg) of pollutant emitted per million (10^6) grams (Mg) of product.

Very little information is currently available in AP-42 relating to applicable size-specific emission factors for various processes. Therefore, it is frequently necessary to obtain additional test data on the typical particle sizes associated with the emissions from a particular process to obtain the uncontrolled emission rate of PM_{10}.

To estimate the uncontrolled emission rate of PM_{10} from a particular source, the total particulate emission factor contained in AP-42 is used in Equation 2-2:

$$R_{10} = k\ E_T\ P \qquad (2\text{-}2)$$

where: R_{10} = emission rate of PM_{10} (kg/hr) k = cumulative mass fraction of particulate emissions equal to or less than 10 μmA (%)

E_T = emission factor for total particulate matter (kg/Mg)

P = production rate (or other measure) rate of process operation (Mg/hr)

The term k in Equation 2-2 is determined from the cumulative particle size distribution obtained from appropriate source tests of the process under consideration.

Because of the above lack of emissions data, EPA has recently completed research to develop size-specific emission factors for selected point sources. In this effort, revised AP-42 emission factors which specifically address PM_{10} are being developed for various industrial processes. The industries included in this program are: Portland Cement Manufacturing; Lime Manufacturing; Asphaltic Concrete Plants; External Combustion; Pulp and Paper Mills; Nonferrous Metallurgical Operations; Iron and Steel Production; Ferroalloy Production; Gray Iron Foundries; and Metallurgical Coke Production. Of those industries listed, the size-specific emission factors for asphaltic concrete plants and pulp and paper mills are the most highly refined and should be published in AP-42 sometime in the near future. The remainder are still at various stages in the EPA peer review process.

Whenever size-specific emission factors are available, Equation 2-2 reduces to:

$$R_{10} = E_{10}P \qquad (2\text{-}3)$$

where: E_{10} = the emission factor for PM_{10}; and R_{10} and P are as shown in Equation 2-2 above

2.2 PROCESS FUGITIVE EMISSION FACTORS

Applicable emission factors have also been published in AP-42 for process fugitive emissions. As with ducted source emissions, Equations 2-2 and 2-3 shown above would likewise apply to process fugitive sources as well.

In many instances, process fugitives are emitted into a building or other enclosure and thus reach the atmosphere indirectly through various openings such as roof monitors, windows, doors, etc. The sampling techniques used to quantify such emissions are, therefore, much more difficult to implement than is the case of ducted sources.[2] Care should thus be exercised whenever applying the appropriate emission factor for the various process fugitive sources outlined in AP-42.

To assist the analyst in the above determination, one additional reference document might prove useful. This document is entitled, "Technical Guidance for Control of Industrial Process Fugitive Particulate Emissions (EPA-450/3-77-010)."[3] Although this particular reference is somewhat dated, it does discuss, in some detail, the emissions from various process fugitive sources of interest.

2.3 OPEN SOURCE EMISSION FACTORS

In 1972 under contract to EPA, Midwest Research Institute (MRI) initiated field testing programs to develop emission factors for four major categories of open dust sources: aggregate storage piles, unpaved roads, agricultural tilling, and heavy construction operations. Because the emission factors were to be applicable on a nation-wide basis, an analysis of the physical mechanisms of fugitive dust generation was performed to ascertain the parameters which would cause emissions to vary from one location to another. These parameters were found to be grouped into three basic categories:

1. Measures of source activity or energy expended (e.g., the vertical fall distance during a material transfer operation; vehicle weight and speed on unpaved roads; etc.).

2. Properties of the material being disturbed (e.g., the amount of suspendable fines (or silt) and moisture content of the material being dropped).

3. Climatic parameters (e.g., the wind speed to which the material is exposed).

Uncontrolled emissions within a single generic source category may vary over two (or more) orders of magnitude as a result of variations in source conditions (equipment characteristics, material properties, and climatic parameters). Therefore, an entire generic source category cannot be represented in terms of a single-valued emission factor as is the case for ducted sources. Rather, a large matrix of single-valued factors is necessary to adequately represent an entire open dust source category. In order to account for the variability in emissions, fugitive dust emission factors were constructed as mathematical equations for sources grouped by dust generation mechanism. The emission factor equation for each source category contains correction terms which explain much of the variance in observed emissions on the basis of specific source parameters. Such factors are applicable to a wide range of source conditions, limited only by the extent of experimental verification.

For example, the use of the silt content as a measure of the dust generation potential of a material extends the applicability of the emission factor equations to the wide variety of aggregate materials of industrial importance. The silt content is obtained by dry sieving through a 200 mesh screen according to ASTM Method C-136. The upper size limit of silt particles (74 µm in physical diameter) is the smallest particle size for which size analysis by dry sieving is practical, and is also a reasonable estimation of the upper size limit for particles which can become airborne.

In 1975, EPA published a new section of AP-42 (Section 11.2) dealing with fugitive dust sources on a generic basis and incorporating newly developed emission factors. The original source categories included unpaved roads, agricultural tilling, and aggregate storage piles. As a result of the increased rate of open dust source test data accumulation after 1975 and the development of improved emission factors, EPA published a major update and expansion of Section 11.2 (Supplement 14) in May 1983. This included improved emission factor equations for unpaved roads, agricultural tilling, industrial paved roads, aggregate storage piles, and materials handling (including batch and continuous drop operations). The agricultural tilling equation was again updated in Supplement 15 published in January of 1984.

With each of the new fugitive emission factors was provided a set of correction parameters for adjusting calculated emission values to specific particle size fractions. The largest factor corresponds to particles equal to or less than 30 μm in aerodynamic diameter corresponding to the approximate effective cutpoint of the standard high-volume sampler (i.e., total suspended particulate matter or TSP). A size factor for particles equal to or less than 10 μm aerodynamic diameter is also provided, which is directly applicable to EPA's proposed revision to the primary NAAQS.

2.3.1 Predictive Emission Factor Equations

The following sections describe the current (or soon to be published) AP-42 emission factor equations applicable to the following fugitive dust source categories: unpaved roads, paved roads, aggregate handling and storage piles, and construction operations. Also discussed are appropriate correction parameters to be used as input to the equations. References to the origin of the equations and supporting information are (or will be) provided in AP-42.

2.3.1.1 Unpaved Roads--

The following empirical expression may be used to estimate the quantity of particulate emissions from an unpaved road per unit of vehicle travel:[1]

$$E = 1.7k \left(\frac{s}{12}\right) \left(\frac{S}{48}\right) \left(\frac{W}{2.7}\right)^{0.7} \left(\frac{w}{4}\right)^{0.5} \left(\frac{365-p}{365}\right) \quad \text{(kg/VKT)} \qquad (2\text{-}4a)$$

$$E = 5.9k \left(\frac{s}{12}\right) \left(\frac{S}{30}\right) \left(\frac{W}{3}\right)^{0.7} \left(\frac{w}{4}\right)^{0.5} \left(\frac{365-p}{365}\right) \quad \text{(lb/VMT)} \qquad (2\text{-}4b)$$

where: E = emission factor (kg/VKT or lb/VMT)

k = particle size multiplier (dimensionless) = 0.45 for PM_{10}

s = silt content of road surface material (%)

S = mean vehicle speed (km/hr or mph)

W = mean vehicle weight (Mg or tons)

w = mean number of wheels (dimensionless)

p = number of days with at least 0.254 mm (0.01 in.) of precipitation per year

The number of wet days per year (p) for the geographical area of interest should be determined from local climatic data. Figure 2-1 gives the geographical distribution of the mean annual number of wet days per year in the United States.

Equation 2-4 has an A quality rating if applied within the ranges of source conditions that were tested in developing the equation, as shown in Table 2-1. Also, to retain the quality rating of Equation 2-4 applied to a specific unpaved road, it is necessary that reliable correction parameter values for the specific road in question be determined. The field and laboratory procedures for determining road surface silt content are given in Appendices A and B and for determining traffic and vehicle characteristics in Appendix C.

Equation 2-4 was developed for calculation of annual average emissions, and thus, is to be multiplied by annual source extent in vehicle distance traveled (VDT). Annual average values for each of the correction parameters are to be substituted into the equation. Worst case emissions, corresponding to dry road conditions, may be calculated by setting p = 0 in the equations (which is equivalent to dropping the last term from the equations). A separate set of nonclimatic correction parameters and a higher than normal VDT value may also be justified for the worst case averaging period (usually 24 hr).

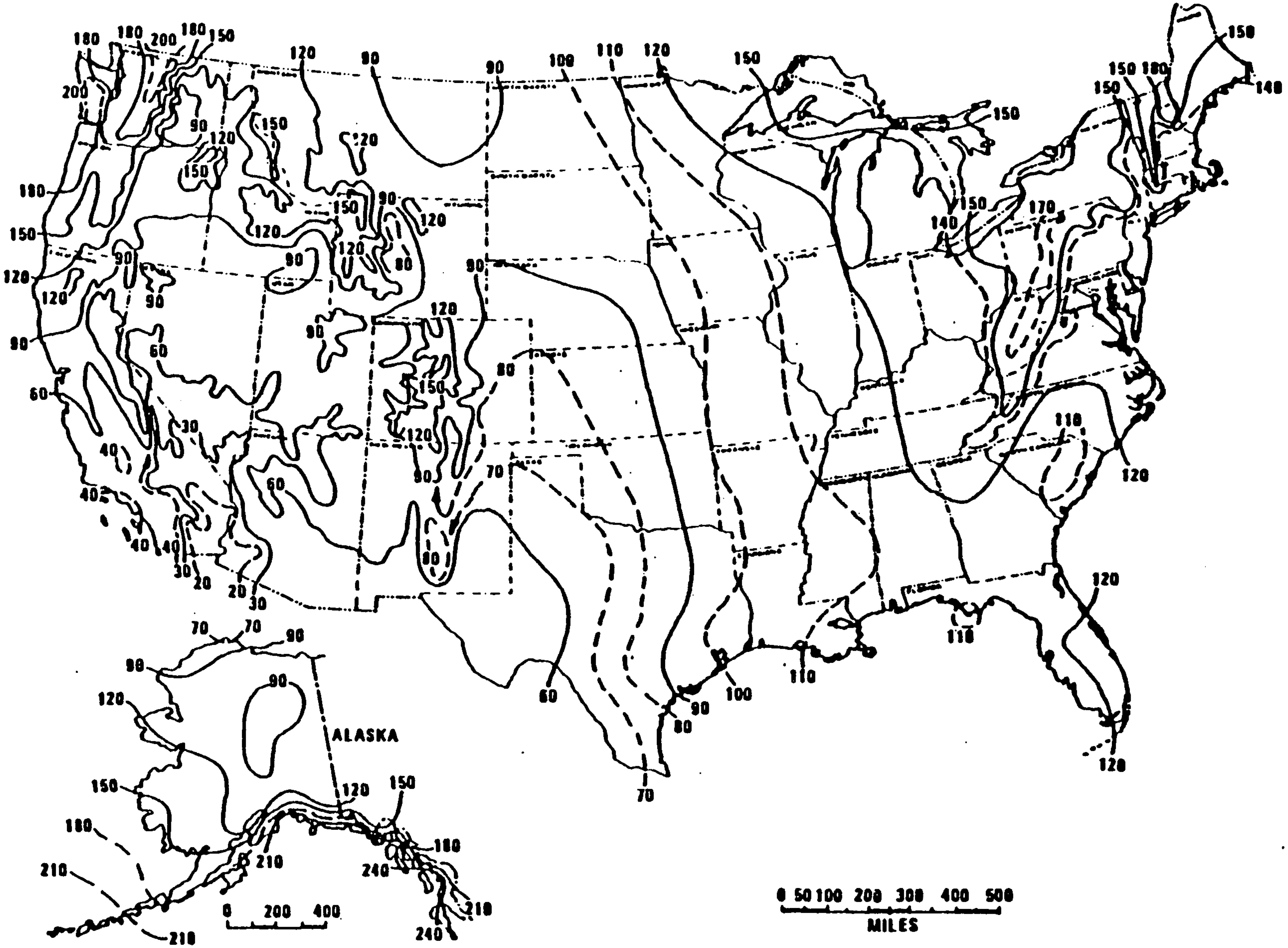

Figure 2-1. Mean number of days with 0.01 in. or more of precipitation in United States.[1]

TABLE 2-1. RANGE OF SOURCE CONDITIONS FOR EQUATION 2-4[a]

Road surface silt content (%)	Mean vehicle weight		Mean vehicle speed		Mean No. of wheels
	Mg	tons	km/hr	mph	
4.3 - 20	2.7 - 142	3 - 157	21 - 64	13 - 40	4 - 13

[a] Values must be in the stated ranges to maintain A quality rating. Reference 1.

Similarly, to calculate emissions for a 91 day season of the year using Equation 2-4, replace the term (365-p)/365 with the term (91-p)/91, and set p equal to the number of wet days in the 91 day period. Also, use appropriate seasonal values for the nonclimatic correction parameters and for VDT.

2.3.1.2 Paved Roads--

The quantity of particulate emissions generated by vehicle traffic on dry, industrial paved roads, per unit of vehicle travel, may be estimated using the following empirical expression:

0.022Ik

$$E = 0.025k \left(\frac{4}{n}\right) \left(\frac{s}{10}\right) \left(\frac{L}{280}\right) \left(\frac{W}{2.7}\right)^{0.7} \quad \text{(kg/VKT)} \qquad (2\text{-}5a)$$

0.077Ik

$$E = 0.090k \left(\frac{4}{n}\right) \left(\frac{s}{10}\right) \left(\frac{L}{1,000}\right) \left(\frac{W}{3}\right)^{0.7} \quad \text{(lb/VMT)} \qquad (2\text{-}5b)$$

where: E = emission factor (kg/VKT or lb/VMT)

k = particle size multiplier (dimensionless) = 0.51 for PM_{10}

I = industrial augmentation factor (dimensionless)

n = number of traffic lanes (dimensionless)

s = surface material silt content (%)

L = surface dust loading (kg/km or lb/mile)

W = average vehicle weight (Mg or tons)

The industrial road augmentation factor (I) in the equation is an empirical factor which takes into account higher emissions from industrial roads than from urban roads. I = 7.0 for an industrial roadway which traffic enters from unpaved areas. I ≐ 3.5 for an industrial roadway with unpaved shoulders which are traveled by 20% of the traffic. I = 1.0 for cases in which traffic does not travel on unpaved areas. A value of I between 1.0 and 7.0 should be used in the equation which best represents conditions for paved roads at a certain industrial facility (see Appendix C for details on the determination of I).

The equation has a quality rating of B if applied to vehicles traveling entirely on paved surfaces (I = 1.0) and if applied within the range of source conditions that were tested in developing the equation as shown in Table 2-2.

TABLE 2-2. RANGE OF SOURCE CONDITIONS FOR EQUATION 2-5[a]

Silt content (%)	Surface loading		No. of lanes	Vehicle weight	
	kg/km	lb/mile		Mg	tons
5.1 - 92	42.0 - 2,000	149 - 7,100	2 - 4	2.7 - 12	3 - 13

[a] Values must be in the stated ranges to maintain a B quality rating with I = 1. Reference 1.

If I > 1.0, the rating of the equation drops to D because of the arbitrariness in the guidelines for estimating I (see Appendix C). Also, to retain the quality ratings of Equation 2-5 applied to a specific industrial paved road, it is necessary that reliable correction parameter values for the specific road in question be determined. The field and laboratory procedures for determining surface material silt content and surface dust loading are given in Appendices A and B.

For urban paved roads, a revised emission factor equation has been developed which should be published in AP-42 in the very near future.[4] The quantity of PM_{10} generated by vehicle traffic on an urban paved roadway per vehicle kilometer traveled (VKT) may be estimated using the following empirical expression[4]:

$$E = 2.28 \left(\frac{sL}{0.5}\right)^{0.8} \tag{2-6}$$

where: E = PM_{10} emission factor (g/VKT)

S = surface material silt content (%)

L = total surface dust loading (g/m^2)

For most emissions inventory applications involving urban paved roads, actual measurements of silt loading will probably not be made. Therefore, to facilitate the use of the previously described equation, it is necessary to characterize silt loadings according to parameters readily available to persons developing the inventories. It is convenient to characterize variations in silt loading with a roadway classification system presented in Table 2-3.[4] This system generally corresponds to the classification systems used by transportation agencies, and thus the data necessary for an emissions inventory (number of road miles per road category and traffic counts) should be easy to obtain. In some situations, it may be necessary to combine this silt loading information with sound engineering judgment in order to approximate the loadings for roadway types not specifically included in Table 2-3.

A data base of 44 samples analyzed according to consistent procedures may be used to characterize the silt loadings for each roadway category.[4] These samples, obtained during recent field sampling programs, represent a broad range of urban land use and roadway conditions. Geometric means for this data set are given by sampling location and roadway category in Table 2-4.[4]

TABLE 2-3. PAVED URBAN ROADWAY CLASSIFICATION[a]

Roadway category	Average daily traffic (ADT)	No. of Lanes
Freeways/expressways	> 50,000	≧ 4
Major streets/highways	> 10,000	≧ 4
Collector streets	500 - 10,000	2[b]
Local streets	< 500	2[c]

[a] Reference 4.

[b] Road width ≧ 32 ft.

[c] Road width < 32 ft.

TABLE 2-4. SUMMARY OF SILT LOADING (sL) VALUES FOR PAVED URBAN ROADWAYS[a]

	Roadway category							
	Local streets		Collector streets		Major streets/highways		Freeways/expressways	
City	$\bar{X}_g$(g/m²)	n	$\bar{X}_g$(g/m²)	n	$\bar{X}_g$(g/m²)	n	$\bar{X}_g$(g/m²)	n
Baltimore	1.42	2	0.72	4	0.39	3	-	-
Buffalo	1.41	5	0.29	2	0.24	4	-	-
Granite City (IL)	-	-	-	-	0.82	3	-	-
Kansas City	-	-	2.11	4	0.41	13	-	-
St. Louis	-	-	-	-	0.16	3	0.022	1
All	1.41	7	0.92	10	0.36	26	0.022	1

[a] Reference 4. $\bar{X}_g$ = geometric mean based on corresponding n sample size.

The sampling locations shown in Table 2-4 can be considered representative of most large urban areas in the United States, with the possible exception of those in the Southwest. Except for the collector roadway category, the mean silt loadings do not vary greatly from city to city, though the St. Louis mean for major roads is somewhat lower than those of the other four cities. The substantial variation within the collector roadway category is probably attributable to the effects of land use around the specific sampling locations. It should also be noted that an examination of data collected at three cities in Montana during early spring indicates that winter road sanding may produce loadings five to six times higher than the means of the loadings given in Table 2-4 for the respective road categories.[4]

Finally, Table 2-5 presents PM_{10} emission factors by roadway category obtained by inserting the mean silt loadings in Table 2-4 into Equation 2-6. These emission factors can be used directly for many emission inventory purposes.

TABLE 2-5. RECOMMENDED PM_{10} EMISSION FACTORS FOR SPECIFIC ROADWAY CATEGORIES[a]

Roadway category	PM_{10} Emission factor (g/VKT)
Local streets	5.2
Collector streets	3.7
Major streets/highways	1.8
Freeways/expressways	0.19

[a] Reference 4.

2.3.1.3 Aggregate Handling and Storage Piles--

Total dust emissions from aggregate storage piles are contributions of several distinct activities within the storage cycle:

1. Loading of aggregate onto storage piles (batch or continuous drop operations).
2. Equipment traffic in storage area.
3. Wind erosion of pile surfaces and ground areas around piles.
4. Loadout of aggregate for shipment or for return to the process stream (batch or continuous drop operations).

Adding aggregate material to a storage pile or removing it usually involves dropping the material onto a receiving surface. Truck dumping on the pile or loading out from the pile to a truck with a front end loader are examples of batch drop operations. Adding material to the pile by a stacker conveyor is an example of a continuous drop operation.

The quantity of particulate generated by a <u>batch drop</u> operation per ton of material transferred may be estimated using the following empirical expression:[1]

$$E = 0.0009k \frac{\left(\frac{s}{5}\right)\left(\frac{U}{2.2}\right)\left(\frac{H}{1.5}\right)}{\left(\frac{M}{2}\right)^2\left(\frac{Y}{4.6}\right)^{0.33}} \quad \text{(kg/Mg)} \qquad (2\text{-}7a)$$

$$E = 0.0018k \frac{\left(\frac{s}{5}\right)\left(\frac{U}{5}\right)\left(\frac{H}{5}\right)}{\left(\frac{M}{2}\right)^2\left(\frac{Y}{6}\right)^{0.33}} \quad \text{(lb/ton)} \qquad (2\text{-}7b)$$

where: E = emission factor (kg/Mg or lb/ton)

k = particle size multipler (dimensionless) = 0.36 for PM_{10}

s = material silt content (%)

U = mean wind speed (m/s or mph)

H = drop height (m or ft)

M = material moisture content (%)

Y = dumping device capacity (m^3 or yd^3)

The quantity of particulate emissions generated by a continuous drop operation per ton of material transferred may be estimated using the following empirical expression:[1]

$$E = 0.0009k \frac{\left(\frac{s}{5}\right)\left(\frac{U}{2.2}\right)\left(\frac{H}{3.0}\right)}{\left(\frac{M}{2}\right)^2} \quad (\text{kg/Mg}) \qquad (2\text{-}8a)$$

$$E = 0.0018k \frac{\left(\frac{s}{5}\right)\left(\frac{U}{5}\right)\left(\frac{H}{10}\right)}{\left(\frac{M}{2}\right)^2} \quad (\text{lb/ton}) \qquad (2\text{-}8b)$$

where: E = emission factor (kg/Mg or lb/ton)

k = particle size multiplier (dimensionless) = 0.37 for PM_{10}

s = material silt content (%)

U = mean wind speed measured at 4 m (m/s or mph)

H = drop height (m or ft)

M = material moisture content (%)

Equations 2-7 and 2-8 carry a quality rating of C if applied within the ranges of source conditions that were tested in developing the equations as given in Table 2-6.[1] Also, to retain the quality ratings as applied to a specific facility, it is necessary that reliable correction parameters be determined for the specific sources of interest. The field and laboratory procedures for aggregate sampling are given in Appendices A and B. In the event that site-specific values for correction parameters cannot be obtained, the appropriate mean values from Table 2-6 may be used, but the quality ratings of the equations are reduced to D.

For emissions from equipment traffic (trucks, front end loaders, dozers, etc.) traveling between or on piles, it is recommended that the equation for vehicle traffic on unpaved surfaces be used (see Section 2.3.1.1). For vehicle travel between storage piles, the silt value(s) for the areas among the piles (which may differ from the silt values for the stored materials) should be used.

TABLE 2-6. RANGES OF SOURCE CONDITIONS FOR EQUATIONS 2-7 and 2-8[a]

Equation	Silt content (%)	Moisture content (%)	Dumping capacity		Drop height	
			m³	yd³	m	ft
Batch drop	1.3 - 7.3	0.25 - 0.70	2.10 - 7.6	2.75 - 10	NA ~~1.5~~	NA ~~5~~
Continuous drop	1.4 - 19	0.64 - 4.8	NA	NA	1.5 - 12	4.8 - 39

[a] Values must be in the stated ranges to maintain a C quality rating. NA = not applicable. Reference 1.

For emissions from wind erosion of active storage piles, no PM_{10} emission factor is available in AP-42. The following emission factor equation is recommended for TSP (particles smaller than approximately 30 μmA)[1]:

$$E = 1.9 \left(\frac{s}{1.5}\right)\left(\frac{365-p}{235}\right)\left(\frac{f}{15}\right) \text{ (kg/day/hectare)} \qquad (2\text{-}9a)$$

$$E = 1.7 \left(\frac{s}{1.5}\right)\left(\frac{365-p}{235}\right)\left(\frac{f}{15}\right) \text{ (lb/day/acre)} \qquad (2\text{-}9b)$$

where: E = emission factor

s = silt content of aggregate (%)

p = number of days with ≧ 0.25 mm (0.01 in.) of precipitation per year

f = percentage of time that the unobstructed wind speed exceeds 5.4 m/s (12 mph) at the mean pile height

The coefficient in Equation 2-9 is based on field sampling of emissions from a sand and gravel storage pile area during periods when transfer and maintenance equipment was not operating. Equation 2-9 is rated C for application in the sand and gravel industry and D for other industries.

Worst case emissions from storage pile areas occur under dry windy conditions. Worst case emissions from materials handling (batch and continuous drop) operations may be calculated by substituting into Equations 2-7 and 2-8 appropriate values for aggregate moisture content and for anticipated wind speeds during the worst case averaging period (usually 24 hr). The treatment of dry conditions for vehicle traffic (Equation 2-4) and for wind erosion (Equation 2-9), centering around parameter p, follows the methodology described in Section 2.3.1.1. Also, a separate set of nonclimatic correction parameters and source extent values corresponding to higher than normal storage pile activity may be justified for the worst case averaging period.

2.3.2 Heavy Construction Operations

Heavy construction is a source of dust emissions that may have substantial temporary impact on local air quality. Building and road construction are the prevalent construction categories with the highest emissions potential. Emissions during the construction of a building or road are associated with land clearing, blasting, ground excavation, cut and fill operations, and the construction of the particular facility itself. Dust emissions vary substantially from day to day depending on the level of activity, the specific operations, and the prevailing weather. A large portion of the emissions result from equipment traffic over temporary roads at the construction site.

In estimating the emissions from heavy construction operations, it is necessary to subdivide the site activities into operational steps. Then the emissions from each step are calculated using the emission factor equation that is most applicable. Fortunately, Equation 2-4 is applicable to the typically predominant source (i.e., equipment traffic over unpaved surfaces at the construction site). It should be noted that an important secondary impact of construction operations results from mud carryout and increased dirt loadings on paved roads adjacent to the construction site.

MRI has recently conducted studies of both the emissions generated by construction vehicles and the secondary impacts due to mud/dirt carryout.[5,6] During the first study, an empirical relationship was developed which predicts the downwind concentration of TSP, IP (particles $\leq$ 15 µmA), and PM_{10}

as a function of surface properties and vehicular traffic. The average uncontrolled emission factor developed in the study for TSP was 7.92 kg/vehicle km (28.1 lb/VMT) which would approximately equal 1.6 kg/vehicle km (5.6 lb/VMT) for PM_{10}.[5]

In the second program, the overall increase in emissions due to mud/dirt carryout was estimated for paved roads located adjacent to eight active construction sites in the Minneapolis/St. Paul area. An analysis was conducted using surface samples collected in the field in conjunction with Equation 2-6 above.[6] The results of the study indicated an average emissions increase for PM_{10} to be 12 g/vehicle pass for all eight sites sampled encompassing residential and commercial construction.[6]

2.3.3 Determination of Correction Parameters

Use of the predictive equations presented in Section 2.3.1 improves the accuracy of emission factor estimation over that obtained with single-valued emission factors but requires values for the various correction parameters. The generally higher quality ratings assigned to the equations are applicable only if: (1) reliable values of correction parameters have been determined for the specific sources of interest; and (2) the correction parameter values lie within the ranges tested in developing the equations.

Determination of reliable aggregate and surface material properties requires sampling and analysis of the actual source materials using the techniques referenced in AP-42. Those techniques are described in Appendices A and B. In the event that the source materials cannot be sampled (e.g., in the case of a proposed new facility), a limited number of default values may be obtained from the tables presented in AP-42. However, use of a default value from these tables reduces the quality rating of the emission factor estimate by one level.

Tables 2-7, 2-8, and 2-9 present ranges and mean correction parameter values for unpaved road surface materials, industrial paved road surface materials, and industrial aggregate materials, respectively.[1,4] Mean values of the correction parameters provided in these tables can be used as appropriate default values only if:

1. It is impractical or impossible to determine specific correction parameters.
2. Values are available for the industry (and material) in question.
3. There is no reason to believe that the source in question will be atypical of existing sources in the specified industry.

It is generally not permissible to use other than the mean value of the parameter unless some justification is available.

TABLE 2-7. TYPICAL SILT CONTENT VALUES OF SURFACE MATERIALS ON INDUSTRIAL AND RURAL UNPAVED ROADS[1]

Industry	Road use or surface material	No. of test samples	Silt (%) Range	Silt (%) Mean
Iron and steel production	Plant road	13	4.3 13	7.3
Taconite mining and processing	Haul road	12	3.7 - 9.7	5.8
	Service road	8	2.4 - 7.1	4.3
Western surface coal mining	Access road	2	4.9 - 5.3	5.1
	Haul road	21	2.8 - 18	8.4
	Scraper road	10	7.2 - 25	17
	Haul road (freshly graded)	5	18 - 29	24
Rural roads	Gravel	2	12 13	12
	Dirt	1		68

TABLE 2-8. TYPICAL SILT CONTENT AND LOADING VALUES FOR PAVED ROADS AT INDUSTRIAL FACILITIES[a]

Industry	No. of plant sites	No. of samples	Silt (%, w/w) Range	Silt (%, w/w) Mean	No. of travel lanes	Total loading x 10^{-3}[b] Range	Total loading x 10^{-3}[b] Mean	Total loading x 10^{-3}[b] Units	Silt loading (g/m^2) Range	Silt loading (g/m^2) Mean
Copper smelting	1	3	[15.4-21.7]	[19.0]	2	[12.9-19.5] [45.8-69.2]	[15.9] [55.4]	kg/km lb/mi	[188-400]	[292]
Iron and steel production	6	20	1.1-35.7	12.5	2	0.006-4.77 0.020-16.9	0.495 1.75	kg/km lb/mi	< 1.0-2.3	7
Asphalt batching	1	4	[2.6-4.6]	[3.6]	1	[12.1-18.0] [43.0-64.0]	[15.7] [55.7]	kg/km lb/mi	[76-193]	[138]
Concrete batching	1	3	[5.2-6.0]	[5.5]	2	[1.4-1.8] [5.0-6.4]	[1.7] [5.9]	kg/km lb/mi	[11-12]	[12]
Sand and gravel processing	1	3	[6.4-7.9]	[7.1]	1	[2.8-5.5] [9.9-19.4]	[3.8] [13.3]	kg/km lb/mi	[53-95]	[70]

[a] Reference 4. Brackets indicate values based on samples obtained at only one plant site.

[b] Multiply entries by 1,000 to obtain stated units.

TABLE 2-9. TYPICAL SILT AND MOISTURE CONTENT VALUES OF MATERIALS AT VARIOUS INDUSTRIES[1]

Industry	Material	Silt (%)			Moisture (%)		
		No. of test samples	Range	Mean	No. of test samples	Range	Mean
Iron and steel production	Pellet ore	10	1.4 - 13	4.9	8	0.64 - 3.5	2.1
	Lump ore	9	2.8 - 19	9.5	6	1.6 - 8.1	5.4
	Coal	7	2 - 7.7	5	6	2.8 - 11	4.8
	Slag	3	3 - 7.3	5.3	3	0.25 - 2.2	0.92
	Flue dust	2	14 - 23	18.0	0	NA	NA
	Coke breeze	1		5.4	1		6.4
	Blended ore	1		15.0	1		6.6
	Sinter	1		0.7	0	NA	NA
	Limestone	1		0.4	0	NA	NA
Stone quarrying and processing	Crushed limestone	2	1.3 - 1.9	1.6	2	0.3 - 1.1	0.7
Taconite mining and processing	Pellets	9	2.2 - 5.4	3.4	7	0.05 - 2.3	0.96
	Tailings	2	NA	11.0	1		0.35
Western surface coal mining	Coal	15	3.4 - 16	6.2	7	2.8 - 20	6.9
	Overburden	15	3.8 - 15	7.5	0	NA	NA
	Exposed ground	3	5.1 - 21	15.0	3	0.8 - 6.4	3.4

NA = Not Available

To provide some further guidance in selecting representative correction parameters for vehicle characteristics, wind speeds, drop heights, and dumping capacities, Tables 2-10, 2-11, and 2-12 are typical values determined during various field testing programs.[7-20] These may also be used to estimate appropriate inputs for similar operations where no actual data are available.

TABLE 2-10. TYPICAL CORRECTION PARAMETERS DETERMINED FOR UNPAVED ROADS

Industry	Type of vehicular traffic	Vehicle speed (km/hr)	Vehicle weight (Mg)	Average No. of wheels	Reference No.	Comments
Iron and steel	Industrial heavy-duty vehicles	23-48	21-64	4-8	7	
	Industrial light-duty	24	3-4	4	8	
	Industrial medium-duty	35-47	7-27	6-13		
	Average vehicle mix (light, med., heavy)	11-18	Light-heavy		9	
Taconite mining and processing	Heavy-duty traffic/ haul trucks	24-32	61-143	6	11	
	Heavy-duty traffic/ average vehicle mix	22	106-107	6		
Western surface coal mining and processing	Vehicle traffic/light-medium duty	40-69	1.8-2.4	4.0-4.1	13	
	Vehicle traffic/haul trucks	24-58	22-125	4.9-10		
	Scrapers/travel mode	16-51	33-64	4.0-4.1		Scraper
	Grading	8.1-19	12-13	5.9-6.0		Grader
	Vehicle traffic/haul trucks	35-39	[a]		14	

(continued)

TABLE 2-10. (concluded)

Industry	Type of vehicular traffic	Vehicle speed (km/hr)	Vehicle weight (Mg)	Average No. of wheels	Reference No.	Comments
Generic unpaved roads	Vehicle traffic	24-64	2-3[b]	4	15	
	Truck traffic/haul roads	16-40	3.9-7.5	6	16	
	Vehicle traffic	16-81	2-3[c]	4	17	
	Vehicle traffic[d]	21-64	3-142	4-13	18	
	Vehicle traffic	11-27	Light-heavy[e]		9	
Agricultural tilling	Agricultural tilling/ tractor speed	5-8[f]			19	Disc, land plane, sweep plow

[a] Information not contained in report.

[b] Actual weights not stated; assume a normal traffic mix weight of 2 to 3 tons.

[c] Test report states normal traffic mix; therefore, the weight range is assumed to be 2 to 3 tons.

[d] Tests were conducted during four different studies ranging from 1973 to 1979.

[e] Actual weights were not assigned to the vehicle weight categories.

[f] Tractor speed.

TABLE 2-11. TYPICAL CORRECTION PARAMETERS DETERMINED FOR INDUSTRIAL PAVED ROADS

Industry	Type of road	Type of vehicular traffic	Industrial road augmentation factor[a]	No. of lanes	Average vehicle weight (Mg)	Reference No.
Iron and steel	Haul road	Average vehicle mix Light/med./heavy	NA	2	6-7	7
	Haul road	Light/med./heavy	NA	2	5-12	8
Asphalt batching	Haul road	Med. duty	NA	1	3.6-3.8	20
Concrete batching	Haul road	Med. duty	NA	2	8.0	20
Copper smelting	Haul road	Med. duty	NA	2	3.1-7.0	20
Sand and gravel processing	Haul road	Heavy duty	NA	1	39-42	20
Paved roads	Haul road	Vehicle traffic	1-7	2-4	3-12	8

[a] This parameter takes into account higher emissions from industrial roads as compared to urban roads.
NA = not available.

I = 7.0 for trucks coming from unpaved to paved roads and releasing dust from vehicle underbodies.
I = 3.5 when 20% of the vehicles are forced to travel temporarily with one set of wheels on an unpaved road berm while passing on narrow roads.
I = 1.0 for traffic entirely on paved surfaces.

TABLE 2-12. TYPICAL CORRECTION PARAMETERS DETERMINED FOR AGGREGATE HANDLING AND STORAGE PILES[a]

Industry	Type of operation	Type of process: Batch	Type of process: Continuous	Type of material	Wind speed (m/sec)	Drop height (m)	Dumping device capacity (m^3)	Reference No.	Comments
Iron and steel	High-silt processed slag/load-out	X		Slag	0.98-1.9	1.5	7.7[b]	7	
	Low silt processed slag/load-out	X		Slag	0.58-1.4	1.5	7.7[b]		
	Ore pile stacking/ mobile conveyor stacker		X	Iron ore pellets	1.0-2.0	1.5-4.5	NA[a]		
	Ore pile stacking/ mobile conveyor stacker		X	Lump ore (desert mound and open hearth)	0.81-0.98	1.5-4.5	NA		
	Conveyor transfer station		X	Sinter	Calm	1.1-2.2	NA		
	Storage pile/ mobile stacker		X	Iron pellets	0.67-2.7	9-12	NA	8	
	Storage pile stacking/ mobile stacker		X	Coal	1.3	5	NA		

(continued)

TABLE 2-12. (continued)

Industry	Type of operation	Type of process: Batch	Type of process: Continuous	Type of material	Wind speed (m/sec)	Drop height (m)	Dumping device capacity (m^3)	Reference No.	Comments
Sand and gravel storage	Active pile activities/ stock piles/ load-in and load-out	X		Sand and gravel	1.1-11.2	1.5	NA	18	· Activity 8-12 hr/24 hr · Wind erosion of pile surfaces and ground area between piles 24 hr · Equipment traffic in storage area · Maintenance
	Inactive wind erosion periods/ load-in and load-out of stockpile material			Sand and gravel	1.1-8.27	1.5	NA		· Equipment traffic in storage area · Wind erosion of pile surfaces and ground area between piles
	Normal mix of active and inactive periods/ load-in and load-out of material stockpiles	X		Sand and gravel	1.1-11.2	1.5	NA		· Equipment traffic in storage area · Wind erosion of pile surfaces and ground area between piles · Assumes 5 active days per week
Stone quarrying and processing	Crushed stone storage piles/high loader/ dump truck	X		Crushed limestone	5.63-6.26	1.5	2	18	

(continued)

TABLE 2-12. (concluded)

Industry	Type of operation	Type of process: Batch	Type of process: Continuous	Type of material	Wind speed (m/sec)	Drop height (m)	Dumping device capacity (m^3)	Reference No.	Comments
Western surface coal mining and processing	Dragline	X		Overburden	0.18-0.80	NA	14	12	Test conducted in northwest Colorado
	Dragline	X		Overburden	1.4-2.6	NA	57		Test conducted in southwest Wyoming
	Dragline	X		Overburden	1.6-2.4	NA	46		Test conducted in southeast Montana
	Dragline	X		Overburden	2.6-3.2	NA	25		Test conducted in central North Dakota
	Front end loader/ shovel truck	X		Coal loading	0.98-5.01	NA	11-13	13	
	Dragline	X		Overburden	0.98-7.42	2-30	25-50		
Aggregate storage piles and material handling	Batch load-in	X		Steel slag, crushed limestone	0.58-6.26	1.5	2.10-7.65	7	Example: front-end loader to truck
	Storage pile formation/ stacker conveyor/ load-in		X	Coal, lump iron ore, pellets	0.67-2.7	1.5-12	NA	8	

[a] NA = not available.

[b] Front end loader into 35-ton capacity truck.

REFERENCES FOR SECTION 2

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3.0 CONTROL ALTERNATIVES FOR PM_{10}

From Equation 2-1, it is clear that more than one option for reduction of the uncontrolled emission rate can be considered. To begin with, the uncontrolled emission rate is the product of the production rate or source extent and the applicable uncontrolled emission factor. A reduction in either of these variables produces a proportional reduction in uncontrolled emissions.

Although the reduction of production or source extent results in a highly predictable reduction in the uncontrolled emission rate, such an approach usually requires either a reduction or change in the process operation. Frequently, reduction in the extent of one source may necessitate the increase in the extent of another (e.g. shifting of vehicle traffic from an unpaved road to a paved road). The option of reducing production or source extent is very site specific and is thus beyond the scope of this manual. Therefore, such measures will not be discussed further.

A reduction in the uncontrolled emission factor may be achieved by process modifications (in the case of a process) or by adjusted work practices (in the case of open sources). The key to the possible reduction of the uncontrolled emission factor is the knowledge as to how the emissions depend on the source conditions that might be subject to alteration. For open dust sources, this information is embodied in the predictive emission factor equations for fugitive dust sources as presented in Section 2 above. Again, modifications to either the process or in work practices are site specific and thus will not be covered here.

The following sections present various "add-on" alternatives for the control of PM_{10} emissions from both ducted and fugitive sources. The individual methods will be described followed by available control efficiency data for each technique.

3.1 CONTROL ALTERNATIVES FOR DUCTED SOURCES

The control of ducted source PM_{10} emissions involves the application of traditional industrial gas cleaning technology. This technology can be classified into four major categories: mechanical dust collectors; electrostatic precipitators; fabric filters; and wet scrubbers. Devices in each category will be briefly described in this section along with typical size-specific performance data for the collection of PM_{10}. The EPA Control Techniques document listed in Table 1-4 will be utilized as the prime reference in the following discussion.[1]

In addition to the EPA Control Techniques document mentioned above, there are also a number of other standard references which contain specific information on the design and performance of industrial gas cleaning equipment. These references are listed in Table 3-1. The reader is encouraged to consult the documents shown in Table 3-1 for other data pertinent to the engineering design, theory, and collection efficiency associated with various types of point source controls.

3.1.1 Mechanical Dust Collectors

Mechanical collectors comprise a broad class of particulate control devices that utilize gravity settling and dry inertial impaction mechanisms. Because their performance capability is limited to relatively large particles, the use of mechanical collectors for the control of PM_{10} is limited. Thus, mechanical collectors are usually used primarily as precleaners upstream of more efficient devices. Mechanical collectors are reasonably tolerant of high dust loadings, are not susceptible to frequent malfunction if properly designed and operated, and could be adequate control devices for some limited applications.

TABLE 3-1. STANDARD REFERENCE DOCUMENTS FOR INDUSTRIAL GAS CLEANING EQUIPMENT

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There is great diversity in the design and operation of the various types of mechanical collectors. Table 3-2 lists the major types of mechanical dust collectors and the mechanism(s) of particle capture for each type. The following is a brief description of the various mechanical collectors listed in Table 3-2.

TABLE 3-2. MAJOR TYPES OF MECHANICAL DUST COLLECTORS[a]

Collector type	Particle capture mechanism(s)
Settling chamber	Gravity settling
Elutriator	Gravity settling
Momentum separator	Gravity settling, inertial collection
Mechanically aided collector	Inertial collection
Centrifugal collector (cyclone)	Inertial collection

[a] Reproduced from Table 4.2-1 of Reference 1.

Large particulate can be removed by gravitational settling in settling chambers to protect downstream equipment from abrasion and excessive mass loadings. The two basic types are the simple expansion chamber and the multiple tray settling chamber. The latter is comprised of a set of horizontal collection plates that reduce the distance a particle must fall to reach the collecting surface. Thus, a multiple tray unit can collect somewhat smaller particles which settle more slowly.

An elutriator consists of a series of one or more vertical tubes or towers into which a dust-laden gas stream passes at an upward velocity defined by the gas flow rate and the tube cross-sectional area. Large particles with terminal settling velocities greater than the gas velocity are separated and collected at the bottom of the chamber. Smaller particles with a lower settling velocity are carried out of the collector. The particle size collected may be varied by changing the upward gas velocity.

A momentum separator uses a combination of gravity and particle inertia (momentum) to settle particles onto collection surfaces. The particles are separated by providing a sharp change in the direction of gas flow such that momentum carries the particles across the gas streamlines and into the hopper. The simplest versions provide a 90- to 180-degree turn to separate large particles. Baffles can also be added to increase the number of turns and thereby provide a modest increase in collection efficiency.

Like that of momentum collectors, the separation mechanism of mechanically aided separators is inertia. Acceleration of the gas stream increases the effectiveness of inertial separation such that these devices can collect smaller particles than momentum devices. The improved performance is gained, however, at the expense of higher energy cost and abrasion by the action of large diameter particles at medium to high velocities.

Finally, the cyclone collector is similar to the momentum separator in that inertia is used to separate the particles from a turning gas stream. In a cyclone, a vortex is created within the cylindrical section by either injecting the gas stream tangentially or by passing the gas stream through a set of spin vanes. Due to their inertia, the particles migrate across the vortex gas streamlines and concentrate near the cyclone walls. Near the bottom of the cyclone, the gas stream makes a 180-degree turn, and the particles are discharged either downward or tangentially into hoppers below. The treated gas passes upward and out of the cyclone.

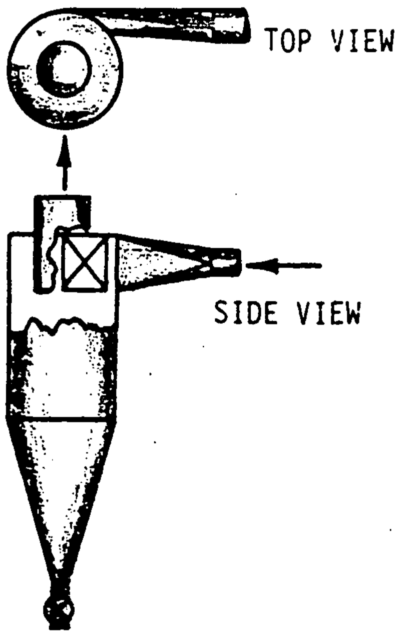
Cyclones can be classified into four basic categories according to the method(s) used to remove the collected dust and to introduce the gas stream into the unit. Figure 3-1 illustrates the four basic types of cyclone collectors.[1] Cyclones can be used as single collectors or as multiple units arranged either in parallel, series, or a combination of both.

3.1.2 Electrostatic Precipitators

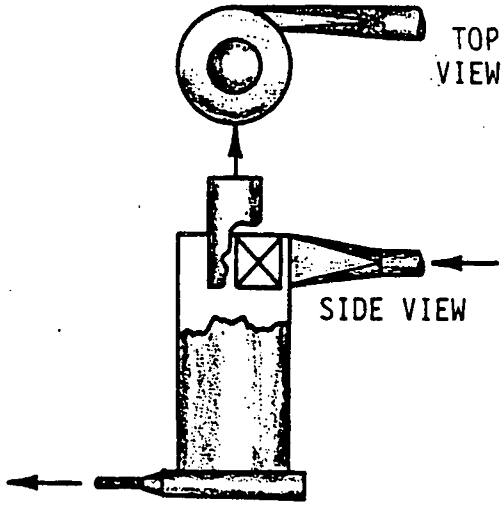
Electrostatic precipitators (ESPs) are high efficiency particulate collection devices applicable to a variety of sources and gas conditions. Particle collection is accomplished by application of electrical energy for particle charging and collection.

There are two broad categories of ESP: one-stage (or Cottrell-type) precipitators; and two-stage units. In a single-stage ESP, particle charging (ionization) and collection are accomplished in a single step, whereas in two-stage units these functions are accomplished separately. One-stage ESPs can be further classified according to electrode geometry (e.g., wire-in-tube versus wire-in-plate type) and type of plate cleaning mechanism (dry versus irrigated). The dry ESP with wire-in-plate electrodes and pyramidal hoppers is the predominant type in industrial applications. Two-stage ESPs are usually limited to air-conditioning applications and the removal of liquid particles in industrial facilities.

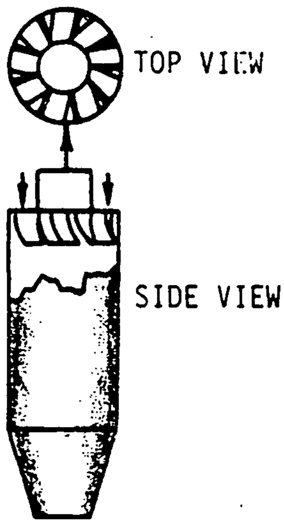
Regardless of the type of precipitator and its geometry, the basic functions of an ESP are to: (1) impart a charge to the particulate; (2) collect the charged particulate on a surface of opposite polarity; (3) remove the collected particulate from the collecting surface in a manner that minimizes reentrainment of the particulate into the gas stream;



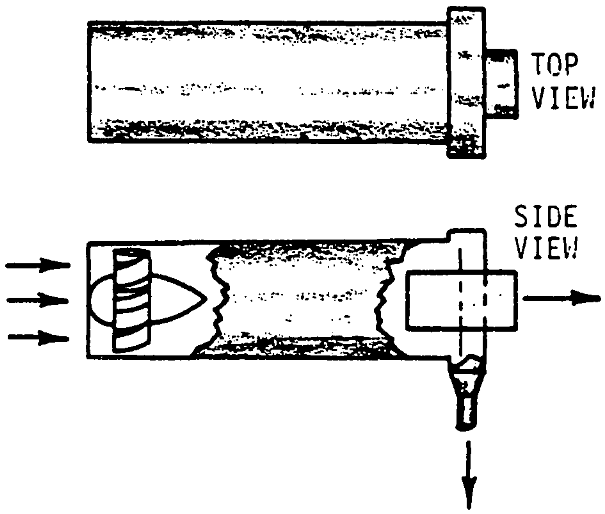
a. Tangential inlet, axial dust outlet



b. Tangential inlet, peripheral dust outlet



c. Axial inlet, axial dust outlet



d. Axial inlet, peripheral dust discharge

Figure 3-1. General types of cyclones.[1]

and (4) discharge the collected particulate from the ESP for subsequent disposal. Each function will be discussed briefly.

To charge the suspended particles, a high-voltage DC current passes through discharge wires producing an electrical corona. A corona can be defined as the ionization of gas molecules by electron collisions in regions of high field strength near the discharge wire.[2] The strength of the electric field varies inversely with the distance from the discharge wire. The corona can be either positive or negative, but negative corona is used in most industrial precipitators since it has inherently superior electrical characteristics that enhance collection efficiency under most operating conditions.

Particle charging and subsequent collection take place in the region between the boundary of the corona glow and the collection electrode, where gas particles are subject to the generation of negative ions (Figure 3-2). Charging is generally done by field and diffusion mechanisms. The dominant charging mechanism varies with particle size.

In general, field charging is most predominant for particles > ~ 0.5 μmA and diffusion charging for particles < ~ 0.2 μmA.[1] The particle size range of about 0.2 to 0.5 μmA is a transitional region in which both mechanisms of charging are present but neither is dominant. Fractional efficiency data for precipitators have shown reduced collection efficiency in this transitional size range, where diffusion and field charging overlap.[1]

An electric field results from application of high voltage to the discharge electrodes with the strength of this electric field being a critical factor in determining ESP performance. Space charge effects from charged particles and gas ions may interfere with generation of the corona and reduce the strength of the electric field. The space charge effect is often seen in the inlet fields of an ESP where particulate concentration is the highest. From a practical standpoint, the strength or magnitude of the electric field is an indication of the effectiveness of an ESP.

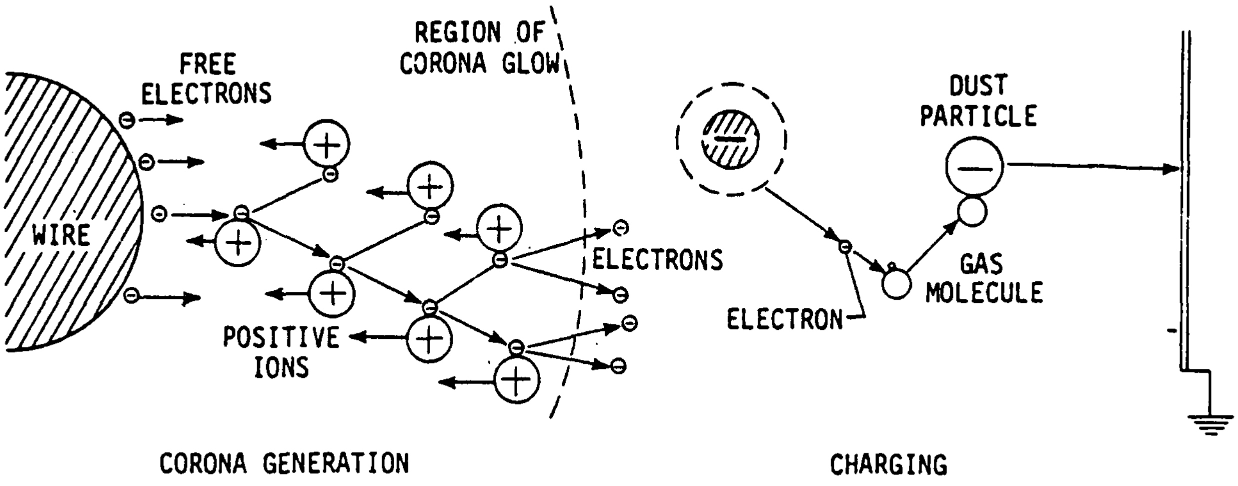


Figure 3-2. Basic processes in electrostatic precipitation.[1]

Corona current flows through the collected dust layer to reach the collection electrode.[1] With dry ESPs, high resistivity affects ESP efficiency by limiting current and voltage. If the electrodes are clean, the voltage can be increased until a sparking condition is reached. The maximum voltage is determined principally by the gas composition and ESP dimensions. When dust is deposited on the collection electrode however, the voltage at which sparking occurs is reduced because of the increased electric field at the dust surface. As dust resistivities increase, the voltage at which sparking occurs decreases. At resistivity values above approximately 10^{12} ohm-cm, the voltage must be reduced so that sparks will not propagate across the interelectrode space. At very low values of current and voltage, dust breakdown can occur. This can result in back corona whereby positive ions form and flow back toward the discharge electrode, neutralizing the negative charge previously applied and thereby limiting ESP performance.

To remove the collected particulate from the collection electrodes, mechanical rappers are used which apply sufficient force to produce a rapid acceleration perpendicular to the gas flow so that the dust layer shears off the plate. Sproull indicates that rapping is optimum if the dust layer slides down the plate vertically after each rap, making its way down the plate in the discrete steps until it finally reaches the hopper.[3]

In addition to reducing the performance of an ESP, high resistivity dust can adhere more strongly to collection electrodes than particles with intermediate resistivity. Therefore, a much greater rapping acceleration must be applied to the electrode to remove the dust. This can cause severe reentrainment or damage to a precipitator that is not designed to withstand such high acceleration.

With a dust that strongly adheres to the plate, vibrations can be induced perpendicularly to the gas flow, in addition to the necessary shear action, resulting in a scattering of the agglomerate and subsequent reentrainment of relatively large fractions of the dust. In general, the dust should be allowed to fall freely off the plate (as sometimes occurs with high resistivity dust when rapping is done with "power off"). The other extreme is with low resistivity dust (e.g., < ~ 10^4 ohm-cm), whose reentrainment can be caused by only a light rap.

The intensity and frequency of rapping are usually greatest at the inlet sections, decreasing as the gas moves through the ESP. The outlet section is usually rapped only lightly, since the reentrained dust is not recollected. The visible puffs that often appear as a result of rapping can be used to optimize the frequency and intensity of rapping for each section of the ESP.

Finally, pyramidal hoppers are routinely used for collection and discharging the particulate. Discharge from hoppers may be accomplished by means of screw, drag, or pneumatic conveying systems. In the pulp and paper industry, flat bottom, tile-lined precipitators that utilize drag conveyors are common on recovery boilers. Solids discharge can represent a significant problem in the operation of an ESP in that excessive buildup of material can cause an electrical shortage or misalignment of ESP internal components.

ESP performance as a function of particle size has been measured at many installations and has been the subject of computer modeling. Probably the most versatile model is the EPA-Southern Research Institute (SoRI) Mathematical Model.[4] This model can be used for sizing and troubleshooting ESPs as well as for predicting penetration (1 - collection efficiency). The reader is referred to the SoRI model for additional assistance in the design, performance, and evaluation of industrial ESPs.

3.1.3 Fabric Filters (Baghouses)

In its simplest form, the industrial fabric filter (baghouse) consists of a woven or felted fabric through which dust laden gases are forced. A combination of factors result in the collection of particles on the fabric fibers. When woven fabrics are used, a dust cake eventually forms which, in turn, provides additional collection sites. When felted fabrics are used, this dust cake is minimal or nonexistent. Instead, the main filtering mechanisms are a combination of inertial forces, electrostatic forces, impingement, etc., as related to individual particle collection on single fiber elements.

As the particulate is collected, pressure drop across the filtering media increases. Because of fan limitations, the filter must be cleaned. This cleaning is accomplished "in-place" since the filter area is usually too large and time between cleanings too short to allow for filter replacement or cleaning external to the baghouse.

Although fabric filters can be classified in a number of ways, the most common is by method of fabric cleaning. The three major categories of fabric cleaning methods are: mechanical shaking; reverse air cleaning; and pulse jet cleaning. Each is described below.

In a conventional shaker-type fabric filter, particulate laden gas enters below the tube sheet and passes from inside the bag to the outside surface. Particles are captured in a dust cake that gradually builds up as filtration continues. At regular intervals, a portion of this dust cake must be removed to enhance gas flow through the filter. The dust cake is removed (manually on small systems and automatically on larger systems) by mechanical shaking of the filter fabric which is normally accomplished by a rapid horizontal motion induced by a shaker bar attached at the top of the bag. The shaking creates a standing wave in the bag and causes flexing of the fabric. The flexing causes the dust cake to crack, and portions are released from the fabric surface. Some of the dust remains on the bag surface and in the interstices of the fabric. Woven fabrics are generally used in shaker-type collectors with the gas flow stopped before cleaning to eliminate particle reentrainment and allow dust cake release. Cleaning may be done by bag, row, section, or compartment.

In reverse air baghouses, particles can be collected in a dust cake either inside or outside of the bag. Regardless of design differences, reverse air cleaning is accomplished by reversal of the gas flow through the filter media. The change in direction causes the surface contour of the filter surface to change (relax) and promotes dust cake cracking. The flow of gas through the fabric assists in removal of the cake. The reverse flow may be supplied by cleaned exhaust gases or by a secondary fan supplying ambient air.

Finally, on pulse jet fabric filters, particle capture is achieved partially on a dust cake and partially within the fabric. Filtering is done on exterior bag surfaces only. During cleaning, a sudden blast of compressed air is injected into the top of the bag. The blast of air creates a traveling wave in the fabric, which shatters the cake and throws it from the surface of the fabric. The cleaning mechanism is classified as fabric flexing and with some degree of reverse airflow. Felted fabrics are normally used in pulse jet-cleaned collectors, and the cleaning intensity (energy) is high. The cleaning normally proceeds by rows, all bags in the row being cleaned simultaneously. The compressed gas pulse, delivered at 550 to 800 kPa results in local reversal of the gas flow.[1] The cleaning intensity is a function of compressed gas pressure. Pulse jet units can operate at substantially higher air-to-cloth (A/C) ratios than the types previously discussed.[1] Typical A/C ranges are 1.5 to 3.0 m^3/m^2-min.[1]

The two factors of basic importance in fabric filter operation are particle capture and static pressure loss. Particle capture mechanisms on a microscopic level are not fully understood. Macroscopic behavior, the net result of all microscopic processes, indicates that fabric filter collection is not highly size dependent as would be expected in view of the collection mechanisms. The static pressure loss results from forcing the gas stream through the fabric and dust cake.

Pore sizes (open areas) of the woven fabric through which the contaminated gas stream passes range from 10 to 100 μm, depending on fabric construction and fiber characteristics.[1] Initially, the particles easily penetrate this filter. As filtration continues, some particles are retained upon filter elements (normally fibers) because of the combined action of the classified collection mechanisms shown in Figure 3-3.[1] As the dust cake builds up, additional "targets" are available to collect particles and penetration drops to very low levels.

Within the dust cake, inertial impaction is the dominant collection mechanism. The forward motion of the particles results in impaction on fibers or on already deposited particles.[1] Although increasing gas velocities favor impaction, they reduce the effectiveness of Brownian diffusion for removal of very small particles. Increasing the fabric porosity also reduces diffusional deposition.[1] As a method of collection, gravity settling of particles is usually assumed to be negligible, although this effect might be considered at low velocities, however.[1]

Electrostatic forces can also affect collection. However, the impact of electrostatic forces in commercial scale equipment is only recently becoming understood. Advanced filter designs now incorporate electrostatic augmentation to achieve high collection efficiencies with reduced pressure drop across the filter media.[5]

Dennis and Klemm have presented a computerized model useful for predicting performance of shaker and reverse air fabric filters. This model is detailed in References 6, 7, and 8. The reader is directed to these documents for additional information on baghouse performance. what kind of info is there?

3.1.4 Wet Scrubbers

Wet scrubbers comprise a set of control devices with similar particle collection mechanisms which primarily include inertial impaction and Brownian diffusion. Accordingly, these scrubber systems generally exhibit strong particle size-dependent performance. Among scrubber types, substantial differences exist with regard to their effectiveness with the greatest differences occurring in the particle size range of 0.1 to 2 μmA.

Scrubber liquids are used for particle collection in several distinct ways. The most common method is to generate droplets, which are then

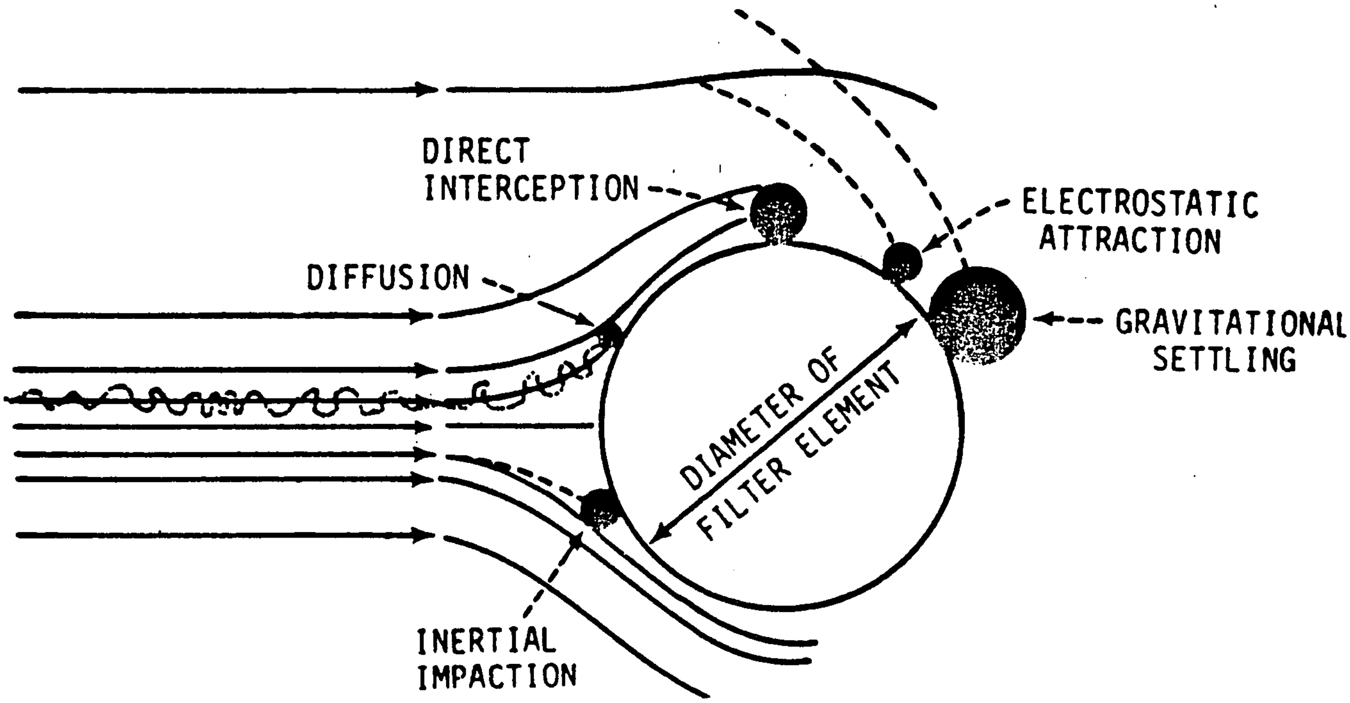


Figure 3-3. Initial mechanisms of fabric filtration.[1]

intimately mixed with the gas stream. Particles are also collected on water layers or sheets surrounding of packing material by directing the particle laden gas stream through an intricate path around the individual packing elements. Á third method is to pass high velocity gas through a vapor to generate "jets" of liquid to collect particles. This is the least common of the three liquid characteristics.

In this discussion, major categories of scrubbers are grouped on the basis of similar mechanisms. The major categories of scrubbers are listed in Table 3-3 in the order of increasing performance capabilities and energy requirements. Each type will be briefly described below.

Preformed spray scrubbers require the least energy of the various scrubbers, and they consequently allow the highest penetration, especially of small diameter particles. Generally, preformed spray units use one or more spray nozzles in a countercurrent or cyclonic flow configuration to remove the incoming particulate by impaction. Most preformed spray scrubbers are highly efficient only for particles larger than 5 μmA in diameter.[1]

In the typical packed bed scrubber, liquid is introduced near the top and trickles down through the packed bed. The liquid flow spreads over the packing into a film with a large surface area. The liquid can be introduced either concurrent or crosscurrent to the gas flow. Packing materials include raschig rings, pall rings, berl saddles, tellerettes, intalox saddles, and materials such as crushed rock.[1] Packed beds can also be constructed with metal grids, rods, or fibrous pads. These scrubbers are often used for gas transfer or gas cooling, both of which are facilitated by the large liquid surface area provided on the packing.[1]

Plugging of a packed bed can occur if the gas to be treated is too heavily laden with solid particles. A general rule for many applications is to limit the use of packed beds to service in which inlet particulate concentrations are less than 0.45 g/m^3.[1] Moving bed scrubbers that have less plugging potential are packed with low density plastic spheres, which are free to move within the packing retainers. Packed bed scrubbers are reported to have low penetration for particle sizes down to 3 μmA and

TABLE 3-3. MAJOR TYPES OF WET SCRUBBERS[a]

Category	Particle capture mechanism	Liquid collection mechanism	Types of scrubbers
Preformed spray	Inertial impaction	Droplets	Spray towers Cyclonic spray towers Vane-type cyclonic towers Multiple tube cyclones
Packed bed scrubbers	Inertial impaction	Sheets, droplets (moving bed scrubbers)	Standard packed bed scrubbers Fiber bed scrubbers Moving bed scrubbers Cross flow scrubbers Grid packed scrubbers
Tray-type scrubbers	Inertial impaction Diffusion	Droplets, jets, and sheets	Perforated plate Impingement plate scrubbers Horizontal impingement plate (baffle) scrubbers
Mechanically aided scrubbers	Inertial interception	Droplets and sheets	Wet fans Disintegrator scrubbers
Gas atomized spray scrubbers	Inertial impaction Diffusion	Droplets	Standard venturi scrubbers Variable throat venturi scrubbers: flooded disc, plumb bob, movable blade, radial flow, variable rod Orifice scrubbers

[a] List not intended to be all inclusive. Reproduced from Table 4.5-1 of Reference 1.

can sometimes remove a significant fraction of particulate in the range of 1 to 2 μmA.[1]

A tray-type scrubber typically consists of a vertical tower with one or more perforated plates mounted transversely inside the shell. In such a scrubber, the liquid and the gas flows countercurrent to one another with the gases being mixed with the liquid passing through the openings in the plates. The perforated plates are often equipped with impingement baffles or bubble caps over the perforations. The gas passing upward through a perforation is forced to turn 180 degrees into a layer of liquid. The gas bubbles through the liquid, and particulate is collected in the liquid sheet. The impingement baffles are below the liquid level on the perforated plates and are, therefore, continuously washed clean of collected particles. Penetration through a typical impingement plate is low for particles larger than 1 μmA, but penetration of submicrometer particulate is higher than with some higher energy scrubbers.[1]

Mechanically aided scrubbers utilize a mechanical rotor or fan to shear the scrubbing liquid into dispersed droplets. These scrubbers use a specially designed stator and rotor arrangement to produce very fine liquid droplets that are effective in the capture of fine particulate. The low penetration of fine particulate, however, is achieved at a high energy cost.[1] Because both wet fan and disintegrator-type scrubbers are subject to particulate buildup or erosion at the rotor blades, they are often preceded by precleaning devices for removing coarse particulate.[1] Mechanically aided scrubbers generally do not perform well with inlet particulate loadings in excess of 1 g/m^3.[1]

Finally, venturi and orifice scrubbers (gas-atomized spray scrubbers) are perhaps the most common particulate removal devices in that they have the highest collection efficiency for small particles as compared to most other types of scrubbers. These scrubbers accomplish fine particulate collection by generating small liquid droplets in the turbulent zone which creates a high relative velocity between the droplets and the particulate. Inertial capture of particulate by the scrubbing liquid is more efficient in these highly turbulent processes, but a price is paid in energy consumption to achieve the low penetration.

Analysis of the particle collection capability of wet scrubbers can be based on: (a) the fundamental particle collection mechanisms; and (b) the empirical contact power approach. The latter method is based on the premise that penetration is proportional to the power expended in the scrubber.[1] This premise is logical because high energy consumption implies high relative gas-water velocities, high water utilization, and fine droplet formation, all of which favor impaction, the dominant collection mechanism. Limitations of the contact power analysis can be attributed to the difficulty of handling nonideal operating conditions such as poor gas-liquid distribution and particle shattering during high energy scrubbing. Also, this type of analysis is not amenable to situations in which particle collection mechanisms other than inertial impaction are important. Typical pressure drops for various types of wet scrubbers are shown in Table 3-4.

TABLE 3-4. TYPICAL SCRUBBER PRESSURE DROP[a]

Scrubber type	Pressure drop (kPa)
Venturi	1.5 - 18.0
Centrifugal (cyclonic) spray	0.25 - 0.8
Spray tower	0.25 - 0.5
Impingement plate	0.25 - 2.0
Packed bed	0.25 - 2.0
Wet fan	1.0 - 2.0
Self-induced spray (orifice)	0.5 - 4.0
Irrigated filter (filter bed scrubber)	0.05 - 0.8

[a] Reproduced from Table 4.5-3 of Reference 1.

Penetration analyses based on the fundamental particle collection mechanisms involve the identification of the dominant physical phenomenon leading to particle capture. The following is a partial list of the collection mechanisms:

Collection Medium	Capture Phenomenon
Droplets	Inertial impaction Interception Brownian diffusion
Liquid sheets (layers)	Inertial impaction Interception Brownian diffusion Electrostatic attraction
Liquid sheets	Inertial impaction Interception Diffusion
Bubbles	Inertial impaction Interception Brownian diffusion Electrostatic attraction

For each control device, penetration relationships are based on anticipated particle collection mechanisms. The accuracy of the resulting equations depend on the proper assignment of the mechanisms and on the accuracy of the theoretical expressions. Penetration expressions are presented in the Scrubber Handbook (and subsequent documents) for selected types of wet scrubbers.[9,10] The reader is referred to this information for a detailed discussion of such expressions and their theoretical development.

3.1.5 Performance Data for Gas Cleaning Equipment

Limited control efficiency data for PM_{10} are available in the EPA Control Techniques document (Reference 1) for various types of industrial gas cleaning equipment. Typical control efficiency values contained in Reference 1 have been summarized in Tables 3-5, 3-6, and 3-7 for mechanical dust collectors, ESPs/fabric filters, and wet scrubbers, respectively.

Present results from figure 4.2-14 & 4.2-16

TABLE 3-5. TYPICAL PM_{10} CONTROL EFFICIENCIES FOR MECHANICAL DUST COLLECTORS[a]

Type of process	Type of particulate	Type of collector	Collector design/ operating parameters	PM_{10} control efficiency (%)
Sinter plant	Quartz Iron oxide	Settling chamber	Height = 3.05 m Width = 3.05 m Volume = 950 m^3	0 0
Coal-fired boiler[b]	Fly ash	Momentum separator (grit arrestor)	Gravity settling of collected dust	8.6
	Fly ash	Momentum separator (grit arrestor)	Cyclones used for collected dust separation	12
Not specified[b]	ρ = 2 g/cm^3	Simple scroll collector	Collector diameter = 2.1 m Airflow = 396 m^3/min	4.3
		Buell-van Tongeren scroll collector with cyclone dust separation	Unspecified	39
Wood-fired boiler	Wood fly ash	Large-diameter cyclone	Unspecified	23
	Wood fly ash	Multiclone	Unspecified	50

[a] Data taken from pages 4.2-16, 4.2-17, 4.2-19, and 9.2-38 of Reference 1. All values approximate.

[b] Size-efficiency curve obtained from original reference. ? what is orig ref. Give original reference!

TABLE 3-6. TYPICAL PM_{10} CONTROL EFFICIENCIES FOR ELECTROSTATIC PRECIPITATORS AND FABRIC FILTERS[a]

Type of process	Type of particulate	Type of collector	Collector design/ operating parameters[b]	PM_{10} control efficiency (%)
Pulverized coal-fired boiler[c]	Fly ash	Unspecified ESP	SCA = 147 $m^2/m^3/sec$	99.6[f]
Pulverized coal-fired boiler	Fly ash	Unspecified ESP	SCA = 60 $m^2/m^3/min$	96.3
Wet process cement kiln[d]	Clinker	Hot-side ESP	Low voltage operation Irrigated collection electrodes	99.5
Sinter machine windbox[e]	Basicidic sinter	Dry ESP	Unspecified	89.1[f]
Copper reverb. furnace	Metallurgical fume	Unspecified ESP	Unspecified	93.5[f]
Pulverized coal-fired boiler	Fly ash	Reverse-air fabric filter	Pilot-scale unit A/C = 0.85 m/min	99.3

[a] Data on ESPs taken from pages 4.3-20, 9.2-9, 9.7-75, 9.8-32/36, and 9.8-127 of Reference 1. Data on fabric filter taken from page 9.2-9 of Reference 1.

[b] SCA = specific collection area. A/C = air-to-cloth ratio.

[c] Unit firing low sulfur coal.

[d] Gas-fired kiln operating at 97-110% of rated capacity.

[e] Machine equipped with four traveling grate strands with a total production capacity of 5,440 Mg/day.

[f] All values approximate.

TABLE 3-7. TYPICAL PM_{10} CONTROL EFFICIENCIES FOR WET SCRUBBERS[a]

Type of process	Type of particulate	Type of collector	Collector design/ operating parameters[b]	PM_{10} control efficiency (%)
Pulverized coal-fired boiler	Fly ash	Venturi scrubber	Δp = 2.5 kPa	85.2
	Fly ash	CEA variable-throat venturi scrubber	Δp = 4.2 kPa	97.3
Borax-fusing furnace[c]	Borax crystals	Venturi scrubber	Δp = 11 kPa (design)	96.5
Potash dryer	Potash	Multivane scrubber	Δp = 0.78 kPa	59.2
Salt dryer	KCl	Wetted fiber scrubber	Unspecified	87.8
Coke oven[d]	Coke/ volatiles	Venturi scrubber	Δp = 15 kPa	96
Gray iron cupola	Dust/fume	Venturi rod scrubber	Δp = 10-23 kPa	98

[a] Data taken from pages 9.2-9, 9.5-28, 9.5-47, 9.8-27, and 9.8-95 of Reference 1.

[b] Δp = pressure drop across the scrubber.

[c] Furnace operating at 50-75% of rated capacity. Chemical composition of borax is $Na_2B_4O_7 \cdot 10H_2O$.

[d] Pushing operation equipped with a traveling hood system.

The control efficiencies reported in the above tables were taken either from available size-efficiency curves or from tabulated data. Approximate values have been indicated wherever size-efficiency curves were used to calculate the applicable control efficiency (area under the curve) for a particular system. Also, those curves not representing actual test data were deleted from Tables 3-5 through 3-7, as appropriate. If more detailed information is desired to conduct a specific analysis, the reader is directed to the original reference document indicated on the page in Reference 1 noted as footnote (a) of each table.

In addition to Reference 1, the documents listed in Table 3-1 can also be used as resources to obtain PM_{10} control efficiency data for gas cleaning equipment. Another resource is the EPA's Fine Particle Emissions Information System (FPEIS) which is part of the Environmental Assessment Data Systems (EADS) data base.[11,12] The FPEIS provides size-specific test data and process operating parameters for a wide variety of sources and control equipment.

3.2 CONTROL ALTERNATIVES FOR FUGITIVE EMISSIONS

Besides the reduction of source extent and the incorporation of process modifications, there are two basic techniques which can be utilized to control fugitive particulate emissions: prevention of the creation and/or release of particulate matter into the atmosphere; and capture and removal of the particles after they have become airborne.[13]

Selection of suitable control methods depends on the mechanism(s) which generate the particulate emissions and the specific source involved. The methods used to control process sources of fugitive particulate emissions generally take a much different approach from those applied to open dust sources. Differences in source configuration, process requirements, and emissions stream characteristics also affect selection of specific controls.

This section provides information on feasible control techniques for sources of fugitive particulate emissions and available performance data. The basic characteristics of each type of control technique are described, and the types of emission sources amenable to control by the techniques are discussed. Control techniques applicable to the major sources of fugitive particulate defined in Section 1 are identified.

The section is divided into four parts. The first two parts describe preventive and capture/removal control techniques, respectively. The third part identifies the types of controls applicable to open dust and process sources. Finally, the fourth part presents available control performance data taken from Reference 13.

In addition to Reference 13 mentioned above, there are also a number of other references which contain information on the specific application and design of fugitive control systems. These references are listed in Table 3-8. The user is encouraged to consult the documents shown in Table 3-8 for other pertinent data and information on the various types of fugitive source controls.

3.2.1 Preventive Measures

Preventive measures include those measures which prevent or substantially reduce the injection of particulate into the surrounding environment. Preventive measures are independent of whether the particulate is emitted directly into the ambient air, or into the interior of a building. The main types of preventive measures include:[13]

- Passive enclosures (full or partial)
- Wet suppression

TABLE 3-8. ADDITIONAL REFERENCE DOCUMENTS FOR FUGITIVE EMISSION CONTROLS

Kashdan, E. R., et al. Technical Manual: Hood System Capture of Process Fugitive Emissions. EPA Contract No. 68-02-3953, Research Triangle Institute, Research Triangle Park, NC, January 1985.
American Conference of Governmental Industrial Hygienists. Industrial Ventilation, A Manual of Recommended Practice. 18th Edition. Lansing, MI, 1984.
McDermott, H. J. Handbook of Ventilation for Contaminant Control. Fifth Printing, Ann Arbor Science Publishers, Inc., Ann Arbor, MI, 1983.
Danielson, J. A. Air Pollution Engineering Manual. AP-40. U.S. Environmental Protection Agency, Research Triangle Park, NC, May 1973.
Hemeon, W. C. L. Plant and Process Ventilation. The Industrial Press, New York, NY, 1963.
Ohio Environmental Protection Agency. Reasonably Available Control Measures for Fugitive Dust Sources. Columbus, OH, September 1980.
Mukherjee, S. K., and M. M. Singh. Design Guidelines for Improved Water Spray Systems - A Manual. Contract No. J0308017, U.S. Bureau of Mines, Washington, DC, December 1981.

- Stabilization of unpaved surfaces

- Paved surface cleaning

? - Curbing along paved roads

- Work practices

- Housekeeping

Descriptions of control techniques within these five categories are presented below.

3.2.1.1 Passive Enclosures--

A common preventive technique for the control of fugitive particulate emissions is to either fully or partially enclose the source. Enclosures preclude or inhibit particulate matter from becoming airborne due to the disturbance created by ambient winds or by mechanical entrainment resulting from the operation of the source itself. Enclosures also help contain those emissions which are generated. Enclosures can consist of either some type of permanent structure or a temporary arrangement. The particular type of enclosure used is dependent on the individual source characteristics and the degree of control required.

Permanent enclosures are designed to either partially or completely enclose the source by the construction of a building or other structure. Worker safety and housekeeping can become problems in the vicinity of the fugitive emission source controlled by a passive (nonevacuated) enclosure. Types of sources commonly controlled by total enclosures include aggregate storage (bins rather than piles) and external conveyor transport.

Since temporary enclosures take many forms, they are difficult to classify generically. Examples of temporary enclosures are flexible tarpaulin covers over the hatchways of large ocean-going vessels during the loading of grain, or flexible shrouds around truck loading spouts.

A novel variation to the source enclosure method for the control of fugitive particulate emissions involves the application of porous wind fences. Porous wind fences have been shown to significantly reduce emissions from active storage piles and exposed ground areas.[13] The principle employed by wind screens is to provide a sheltered region behind the fenceline which significantly reduces the mechanical turbulence generated by ambient winds in an area the length of which is many times the physical height of the fence. This sheltered region provides for both a reduction in the wind erosion potential of the exposed surface in addition to allowing the gravitational settling of larger particles. The application of wind screens along the leading edge of active storage piles seems to be one of the few good control options which are available for this particular source. A diagram of one type of portable wind screen used at a coal-fired power plant is shown in Figure 3-4.[14]

3.2.1.2 Wet Suppression--

Wet suppression systems apply either water, a water solution of a chemical agent, or a micron-sized foam to the surface of the particulate generating material.[13] This measure prevents or suppresses the fine particles contained in that material from leaving the surface and becoming airborne. If fine water sprays are used to control dust after it has become suspended, this is referred to as plume aftertreatment. Plume aftertreatment (e.g., charged fog) is not a preventive measure but a capture/removal method as discussed below.

The chemical agents used in wet suppression systems can be either surfactants or foaming agents for materials handling and processing operations (e.g., crushers, conveyors) or various types of dust palliatives applied to unpaved roads. In either case, the chemical agent acts to agglomerate and bind the fines to the aggregate surface, thus eliminating or reducing its emissions potential. Each major type of wet suppression method will be described individually.

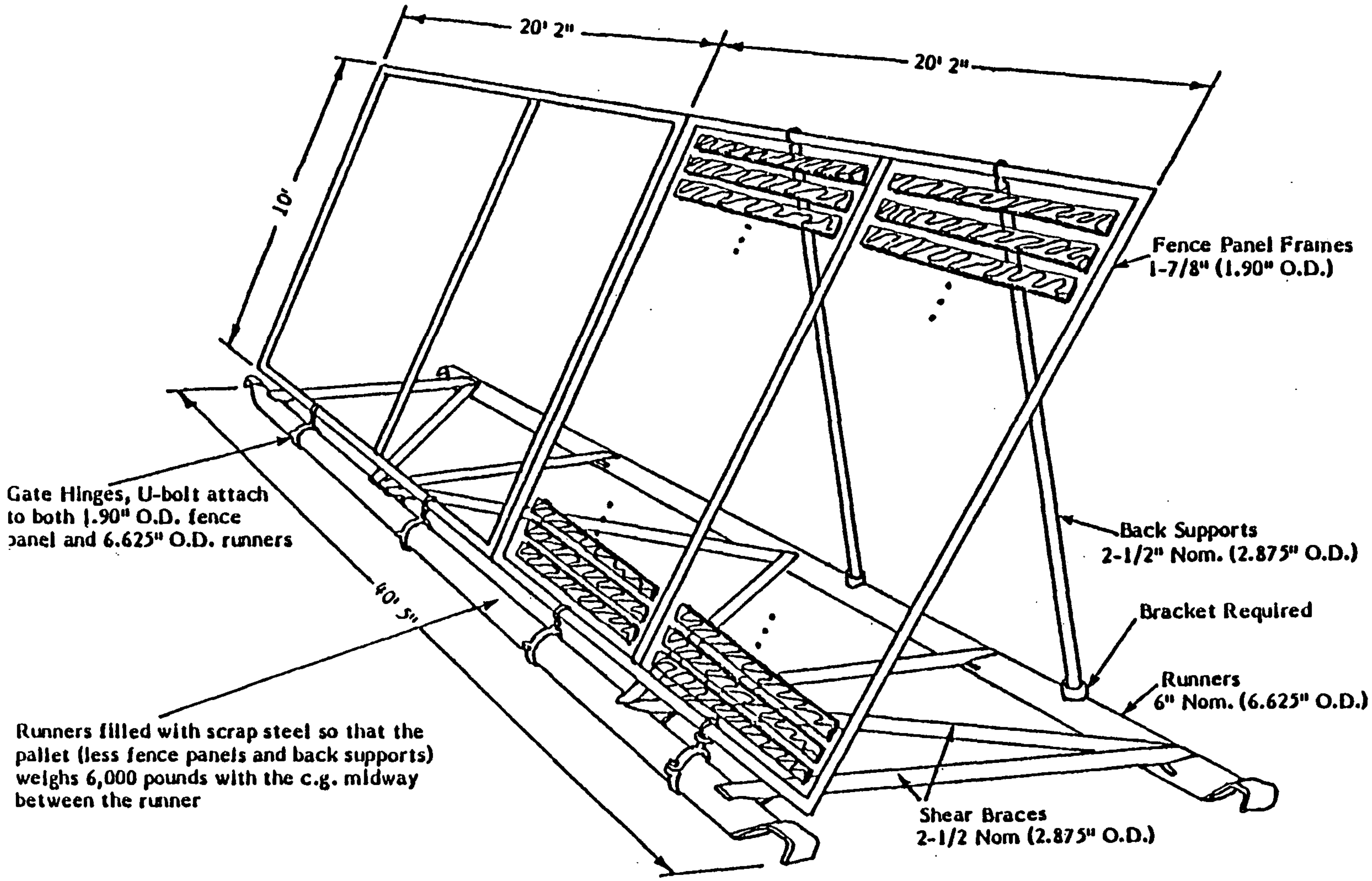


Figure 3-4. Diagram of a portable wind screen.[14]

Wet suppression systems using plain water have been utilized for many years on a variety of sources such as crushing, screening, and materials transfer operations, as well as unpaved roads. For most mechanical equipment, wet suppression involves the use of one or more water sprays to wet the material prior to processing. This technique is usually only temporarily effective, requiring repeated application throughout the process flow.

It should be noted that, in addition to possible freezing problems in the winter, wet suppression with plain water can be used only on those bulk materials which can tolerate a relatively high surface moisture content. In the arid West, wet suppression is not always practical due to inadequate water supplies.

In the case of unpaved roads and parking lots, water is generally applied to the surface by a truck or some other type of vehicle utilizing either a pressurized or a gravity flow system. Again, watering of unpaved roads is only a temporary measure, necessitating repeated application at regular intervals.

To improve the overall control efficiency of wet dust suppression systems, wetting agents can be added to the water to reduce the surface tension. The additives allow particles to more easily penetrate the water droplet and increase the number of droplets, thus increasing the surface area and contact potential.

One of the more recently developed methods used to augment wet suppression techniques is the use of foam to control dust from materials handling and processing operations. The foam is generated by adding a proprietary surfactant compound to a relatively small quantity of water which is then vigorously mixed to produce a small bubble, high energy foam in the 100- to 200-μm size range.[13] The foam uses very little liquid volume and, when applied to the surface of a bulk material, wets the fines more effectively than does untreated water. Foam has been used with good success for controlling the emissions from belt transfer points, crushers, and storage pile load-in.

3.2.1.3 Stabilization of Unpaved Surfaces--

Release of particulate from unpaved surfaces can be reduced or prevented by stabilization of those surfaces. Sources which have been controlled in this manner include unpaved roads and parking lots, active and inactive storage piles, and open areas. Stabilizing mechanisms which have successfully employed include chemical, physical, and vegetative controls. Each of these control types is described below.

The use of chemical dust suppressants for the control of fugitive emissions from unpaved roads has received much attention in the past several years. Chemical suppressants can be classified into six generic categories. These are: (1) salts (i.e., $CaCl_2$ and $MgCl_2$); (2) lignin sulfonate; (3) wetting agents; (4) latexes; (5) plastics; and (6) petroleum derivatives.[13]

Chemical dust suppressants are generally applied to the road surface as a water solution of the agent. The degree of control achieved is a direct function of the application intensity (volume of solution/area), dilution ratio, and frequency (number of applications/unit time) of the chemical applied to the surface and also depends on the type and number of vehicles using the road. Chemical agents have also been proven to be effective as crusting agents for inactive storage piles and for the stabilization of exposed open areas and agricultural fields. In both cases, the chemical acts as a binder to reduce the wind erosion potential of the aggregate surface.

Physical stabilization techniques can also be used for the control of fugitive emissions from unpaved surfaces. Physical stabilization includes any measure, such as compaction of fill material at construction and land disposal sites, which physically reduces the emissions potential of a source resulting from either mechanical disturbance or wind erosion.

The most notable form of physical stabilization of current interest involves the use of civil engineering fabrics or "road carpet" for unpaved roads.[13] In practice, the road carpet fabric is laid on top of a properly prepared road base just below a layer of coarse aggregate (ballast). The fabric sets up a physical barrier such that the fines (< 74 μm in diameter) are prevented from contaminating the ballast layer. These smaller particles are now no longer available for resuspension and saltation resulting from the separation of the fines from the ballast. The fabric is also effective in distributing the concentrated stress from heavy-wheeled traffic over a wider area.

Vegetative stabilization involves the use of various plant species to control wind erosion from exposed surfaces. Vegetative techniques can be used only when the material to be stabilized is inactive and will remain so for an extended period of time. It is often difficult to establish a vegetative cover over materials other than soil because their physical or chemical characteristics are not conducive to plant growth. Resistant strains which can tolerate the composition of the host material sometimes must be developed.

3.2.1.4 Paved Surface Cleaning--

Other than housekeeping, the only method available to reduce the surface loading of fine particles on paved roads is through some form of street cleaning practice. Street sweeping does remove some debris from the pavement thus preventing it from becoming airborne by the action of passing vehicles; but it can also generate significant amounts of finer particulate by the mechanical action used to collect the material.[13]

The three major methods of street cleaning are mechanical cleaning; vacuum cleaning; and flushing.[13] Mechanical street sweepers utilize large rotating brooms to lift the material from the pavement and discharge it into a hopper for later disposal. Broom sweepers are usually effective in picking up only relatively large debris, with a significant portion of the surface material being suspended in the wake of the vehicle (as observed in the field.

Vacuum sweepers remove the material from the street surface by drawing a suction on a pickup head which entrains the particles in the moving air stream. The debris is then deposited in a hopper, and the air is exhausted to the atmosphere. Vacuum units also use gutter brooms to loosen and deflect debris so that it can be picked up. They also have an additional broom which loosens the street dirt and pushes it toward the vacuum nozzles where it is drawn into the storage compartment. A filter system traps the dust and confines it to the sweeper hopper.

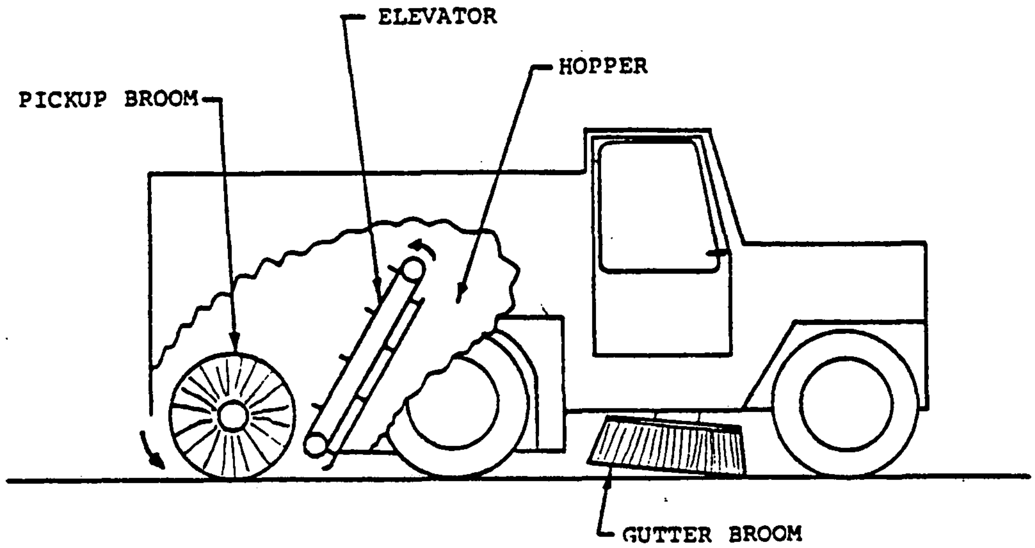
The regenerative sweeper is a vacuum unit with certain significant differences. Cleaning is accomplished by a pickup head with rubber dust curtains at the front. The sweeper usually has a 2.7-m (9-ft) cleaning width.[13] A blower directs a strong blast of air across the pickup head, and the suction from the blower draws the debris into the hopper through a dust separator. Thus, the air circulates continuously through the vacuum sweeper mechanism with no air and little dust exhausted to the atmosphere.

where is collection data?

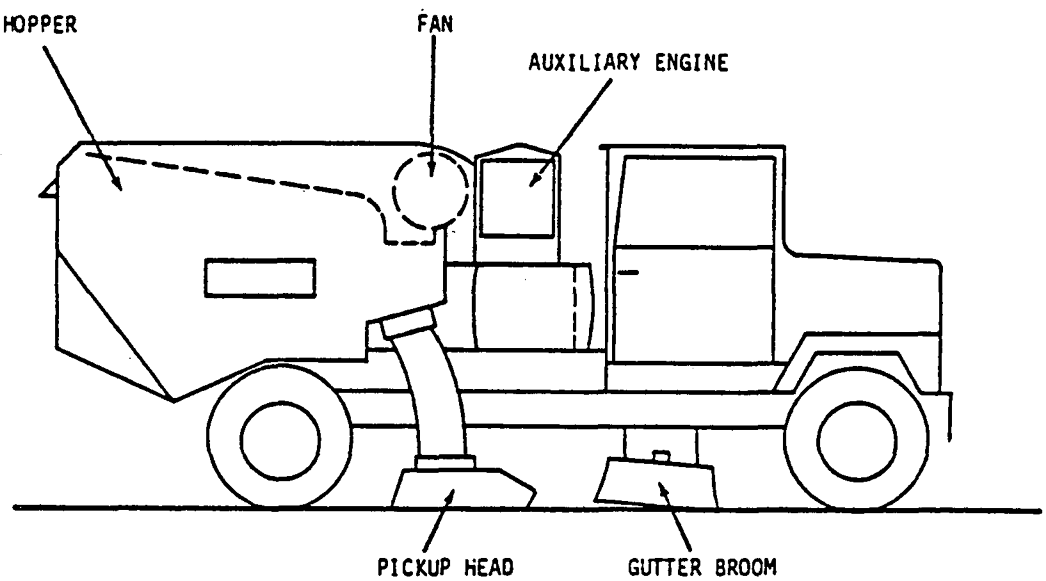
Street flushers hydraulically remove debris from the surface to the gutter and eventually to the storm sewer system through the use of high pressure water sprays. Water storage tanks on flushers vary in capacity from 3,030 to 13,250 L (800 to 3,500 gal.).[13] Flushers have large nozzles, individually controlled, which can be directed either toward the gutter or in a forward direction. Water emerges from the nozzles at pressures of up to 690 kPa (100 psig).[13] This pressure is usually sufficient to scour most debris on the pavement. Flushers have numerous operational disadvantages including the consumption of large quantities of water with the associated potential for water pollution problems. A diagram of both a typical broom sweeper and a regenerative air sweeper is shown in Figure 3-5.[15]

efficiency data?

Want interpretation & recommended efficiencies!



(a) Four-wheeled broom sweeper



(b) Regenerative air vacuum sweeper

Figure 3-5. Diagrams of typical street cleaners.[15]

3.2.1.5 Housekeeping--

Housekeeping generally refers to the removal of exposed dust producing materials on a periodic basis to reduce the potential for dust generation through the action of wind or machinery. Examples of housekeeping measures include: clean-up of spillage on travel surfaces (paved and unpaved); elimination of mud/dirt carryout onto paved roads at construction and demolition sites; and clean-up of material spillage at conveyor transfer points.[13]

Any such method can be employed depending on the source, its operation, and the type of dust-producing material involved. A detailed evaluation is necessary on a case-by-case basis to determine what housekeeping measures can be employed.

3.2.2 Capture Removal Methods

The second basic technique for the control of fugitive particulate emissions includes those methods which capture or remove the particles after they have become airborne. Again, this classification is irrespective of whether such emissions are generated inside or outside of a building. The major types of capture/removal processes include:

- Capture and collection systems

- Plume aftertreatment

The various methods in both categories are described below.

3.2.2.1 Capture and Collection Systems--

Most industrial process fugitive emissions have traditionally been controlled by capture/collection, or industrial ventilation systems. These systems have three primary components: (1) a hood or enclosure to capture emissions that escape from the process; (2) a dust collector that separates entrained particulate from the captured gas stream (see Section 3.1 above);

and (3) a ducting or ventilation system to transport the gas stream from the hood or enclosure to the air pollution control device.

A wide variety of capture methods ranging from total enclosure of the source, to mobile high velocity low volume (HVLV) hoods, to total building evacuation have been employed. Capture devices (or hoods) generally can be classified as one of three types: enclosure, capture hood, or receiving hood. Each type is illustrated in Figure 3-6.[16]

Enclosures, partial or complete, surround the source as much as possible without interfering with process operations. Their predominant feature is that they prevent release of particulate to the atmosphere or working environment. The enclosure is equipped with one or more takeoff ducts to remove particulate that is generated and to maintain a slight negative pressure in the enclosure. Examples of enclosures include enclosed shakeout operations in metal foundries, casings on bucket elevators used for aggregate material transfer, and building evacuation for secondary furnace control.

Capture hoods are located in such a manner that the process is external to the hood. Emissions are actually released to the atmosphere or plant environment and subsequently captured by the hood. Capture hoods have also been referred to as exterior hoods by some authors.[13]

The operating principle of the capture hood is based on capture velocity. The control system must produce a sufficient air velocity at the source to draw the emitted particles to the hood and "capture" the emissions stream. Examples of capture devices are side-draft hoods to capture secondary electric arc furnace emissions, push/pull side-draft hoods to control metal pouring emissions, and side-draft hoods to control cleaning and finishing emissions.

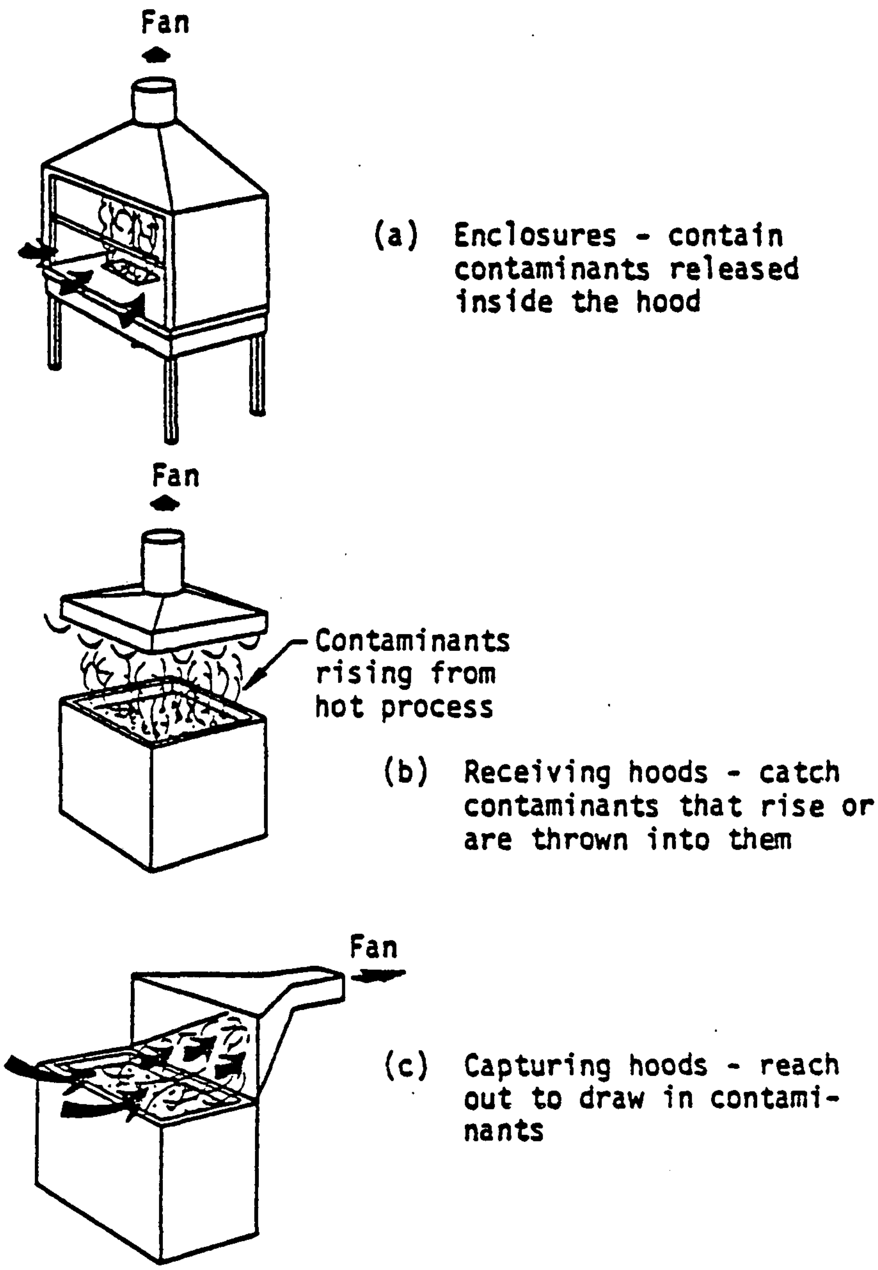


Figure 3-6. General types of capture devices (hoods).[16]

In the case of receiving hoods, emissions from the process are also released to the plant environment or atmosphere prior to entering the hood. However, receiving hoods are designed to take advantage of the inherent momentum of some emissions streams. This momentum is generally a result of thermal buoyancy but also may be a result of inertia generated by the process (e.g., a grinding plume). The system does not need to generate a capture velocity, but it should be designed to exhaust a slightly greater velocity from the hood than the process delivers. Examples of receiving hoods include canopy hoods to capture secondary furnace emissions, close capture hoods located above metal pouring operations, and grinding wheel close capture hoods.

The selection of a suitable capture device is site-specific and depends on both the operating and emissions characteristics of the source. Factors influencing selection include location of the process with respect to other plant operations, degree of process movement (if any), space needed for worker or equipment access to the process, physical size of the operation or process, and momentum of the particulate plume due to buoyancy or inertia applied by the process.

Particulate matter is removed from the gas stream in capture/collection systems by one of four generic types of air pollution control devices: mechanical collectors (or cyclones), wet scrubbers, fabric filters, and electrostatic precipitators (ESPs). As with the capture device, selection of the air pollution control device is site-specific, depending on such factors as: degree of control required to meet regulations or enhance product recovery; availability of excess capacity from an existing control device; feasibility of designing a common device for multiple sources; and various characteristics of the emissions stream. Some of the more important emissions characteristics are particle size distribution, particle resistivity, gas temperature, corrosivity, and chemical composition.

The simplest, and most often neglected, component of the industrial ventilation system is the ductwork or transport system. The transport system must be designed to maintain adequate transport velocities in the ducts and be balanced with respect to pressure drop. Two of the most common causes of malfunctions of capture/collection systems are plugging of the ductwork because of inadequate transport velocities and unbalanced ventilation systems (from either poor design or improper operation) resulting in inadequate capture velocities or exhaust volumes at some processes.[13]

A variation of the traditional capture/collection concept involves the use of air curtains or jets. Air curtains are usually used in those industrial processes which generate a buoyant plume to help isolate it and enhance capture by the emissions control system. One such system is a so-called "push/pull" arrangement. In such an arrangement, an air curtain consisting of a series of jets is used to contain and direct the plume toward some type of capture device. One such system is shown in Figure 3-7 for a copper converter.[17]

3.2.2.2 Plume Aftertreatment--

Plume aftertreatment refers to any system which injects fine water droplets into a dust plume to capture and agglomerate the suspended particles (by impaction and/or electrostatic attraction) to enhance gravitational settling. Plume aftertreatment systems can use water sprays with or without the addition of a chemical surfactant as well as with or without the application of an electrostatic charge (charged fog).

Aftertreatment systems using plain water consist of one or more hydraulic (pressure) or pneumatic (two-fluid) nozzles which create a spray of fine water droplets. When sprayed into the dust plume, these droplets capture and settle the suspended dust particles. This technique has been used extensively for the control of respirable dust in underground mining and similar operations conducted above ground.[13]

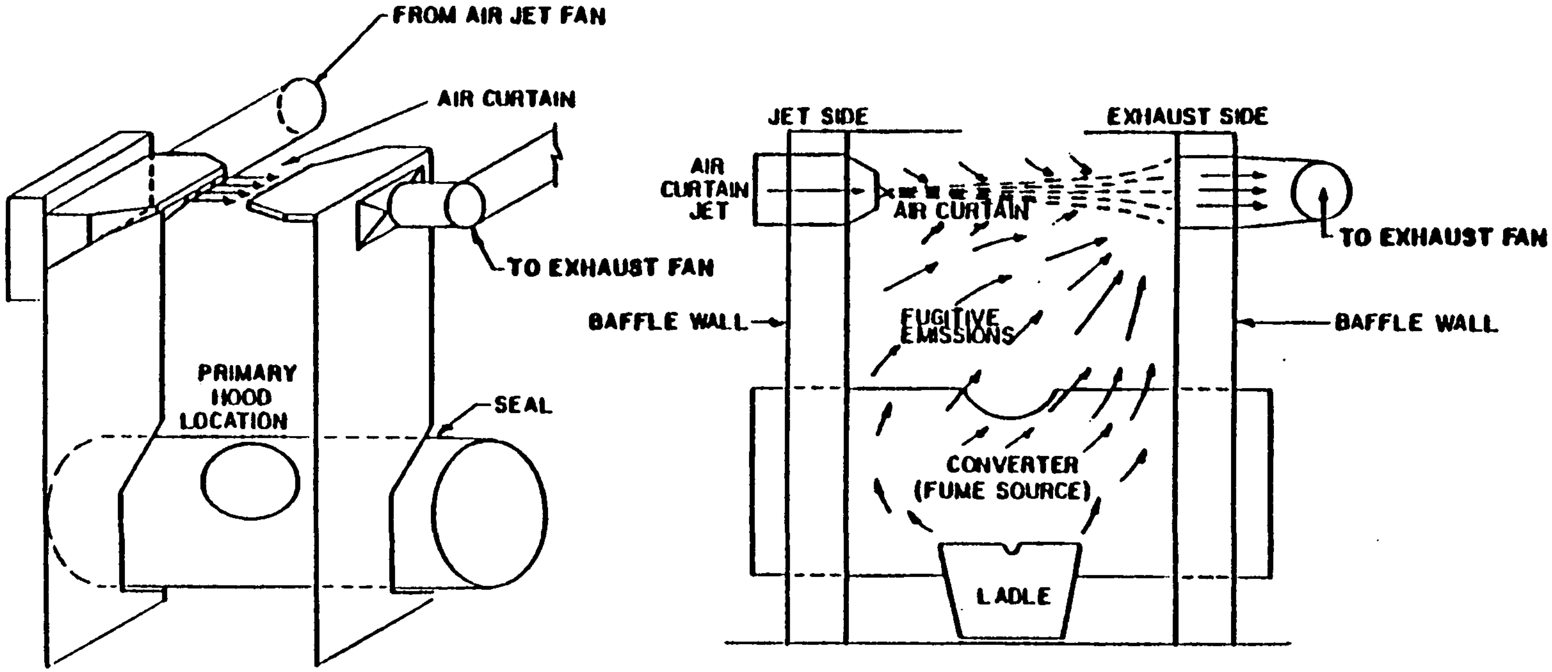


Figure 3-7. Converter air curtain control system.[17]

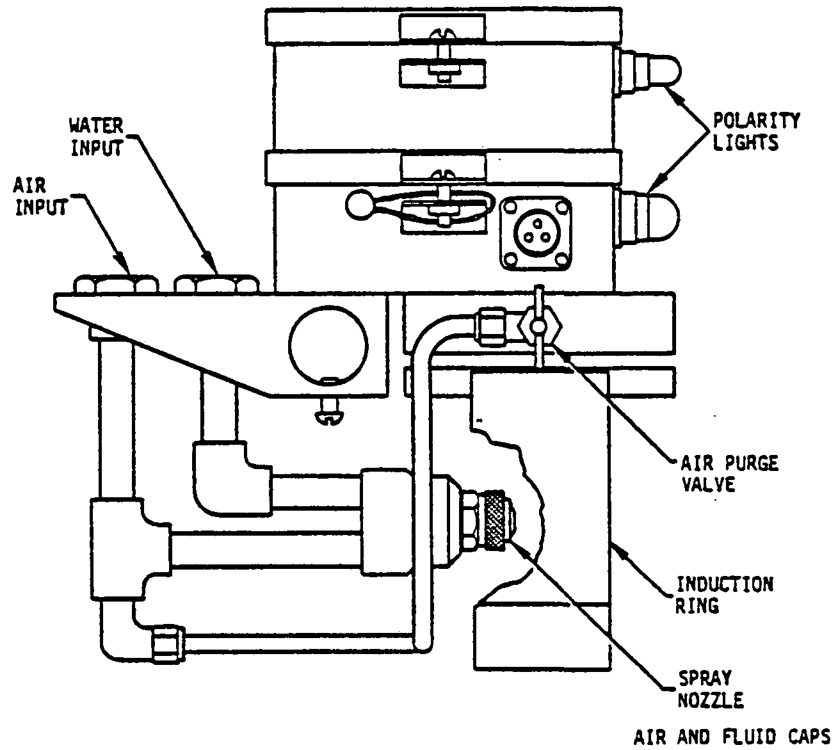
In the past several years, a novel means has been developed to augment traditional water sprays for plume aftertreatment involving the use of electrostatics. Most anthropogenically produced particles normally acquire a slight electrostatic charge.[13] By injecting a fog of oppositely charged water droplets into the plume, a significant enhancement in the capture and removal process can be achieved.[13]

An electrostatic charge is generally applied to a water spray by either of two means. Induction charging applies an electrostatic charge to the droplets by passing the spray through a ring which is isolated at a high voltage. The alternative is to charge the water prior to atomization by direct contact. Of the two methods, contact charging has proven to be much more effective in achieving a higher charge-to-mass ratio. Under heavy spray conditions, induction charging tends to apply a charge only those droplets on the outside of the spray cone. Diagrams of electrostatic foggers using both induction and contact charging are shown in Figure 3-8.[18]

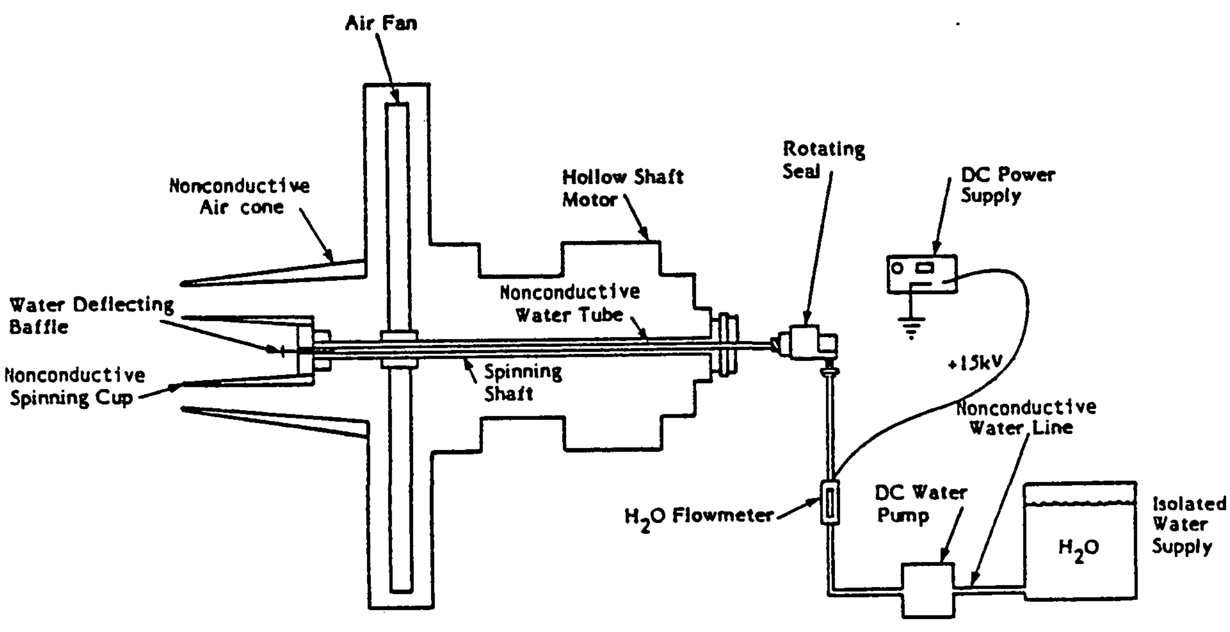
3.2.3 Applicability of Controls to Fugitive Emissions Sources

Process fugitive sources can be controlled by either preventive or capture/removal measures. Principal control measures include wet suppression, capture/collection systems, and plume aftertreatment. Table 3-9 identifies the types of control applicable to process fugitive emissions sources.[13]

Open dust sources are generally controlled by preventive techniques rather than capture/removal techniques. Typical measures used include passive enclosures, wet suppression, stabilization, and surface cleaning. Table 3-10 identifies the types of control measures applicable to each of the generic open dust source categories identified in Section 1.[13]



(a) Electrostatic fogger using induction charging



(b) Electrostatic fogger using contact charging

Figure 3-8. Electrostatic foggers.[18]

TABLE 3-9. PROCESS FUGITIVE PARTICULATE EMISSION SOURCES AND FEASIBLE CONTROL TECHNOLOGY[a]

		Control measure				
			Capture/collection			
Industry	Process source	Wet suppression[b]	Enclosures[c]	Receiving hoods[d]	Capture hoods	Plume after-treatment
Iron and Steel Plants	Coal Crushing/Screening	X		X	X	X
	Coke Ovens			X		
	Coke Oven Pushing		X	X	X	
	Sinter Machine Windbox	X	X	X		
	Sinter Machine Discharge		X	X	X	
	Sinter Cooler		X			
	Blast Furnace Charging					
	Blast Furnace Tapping		X	X		
	Slag Crushing/Screening	X			X	X
	Molten Iron Transfer			X		
	BOF Charging/Tapping/Leaks		X	X		
	Open Hearth Charging/Tapping/Leaks		X	X		
	EAF Charging/Tapping/Leaks		X	X	X	
	Ingot Pouring			X		
	Continuous Casting			X		
	Scarfing		X		X	
Ferrous Foundries	Furnace Charging/Tapping		X	X		
	Ductile Iron Inoculation		X	X		
	Pouring of Molten Metal			X		
	Casting Shakeout		X	X		
	Cooling/Cleaning/Finishing of Castings			X		
	Core Sand and Binder Mixing				X	
	Core Baking			X		
Primary Aluminum Production	Grinding/Screening/Mixing/ Paste Production		X			
	Anode Baking			X		
	Electrolytic Reduction Cell		X	X	X	
	Refining and Casting		X	X	X	
Primary Copper Smelters	Roaster Charging		X	X		
	Roaster Leaks		X			
	Furnace Charging/Tapping/ Leaks		X	X		
Primary Copper Smelters	Slag Tapping/Handling		X	X		
	Converter Charging/Leaks			X		
	Blister Copper Tapping/Transfer		X	X		
	Copper Tapping/Casting		X	X		

(continued)

TABLE 3-9. (continued)

Industry	Process source	Control measure				
			Capture/collection			
		Wet suppression[b]	Enclosures[c]	Receiving hoods[d]	Capture hoods	Plume after-treatment
Primary Lead Smelters	Raw Material Mixing/Pelletizing		X			X
	Sinter Machine Leaks		X	X		
	Sinter Return Handling		X			X
	Sinter Machine Discharge/Screens		X	X		
	Sinter Crushing		X		X	X
	Blast Furnace Charging/Tapping			X		
	Lead and Slag Pouring			X		
	Slag Cooling		X	X		
	Slag Granulator	X	X			
	Zinc Fuming Furnace Vents		X			
	Dross Kettle			X		
	Silver Retort Building		X			
	Lead Casting			X		
Primary Zinc Production	Sinter Machine Windbox Discharge		X	X		
	Sinter Machine Discharge/Screens		X	X		
	Coke-Sinter Mixer		X		X	
	Furnace Tapping		X	X		
	Zinc Casting			X		
Secondary Aluminum Smelters	Sweating Furnace			X		
	Smelting Furnace Charging/Tapping		X	X		
	Fluxing			X	X	
	Dross Handling and Cooling		X	X		
Secondary Lead Smelters	Scrap Burning					
	Sweating Furnace Charging/Tapping		X	X		
	Reverb Furnace Charging/Tapping		X	X		
	Blast Furnace Charging/Tapping		X	X		
	Pot Furnace Charging/Tapping		X	X		
	Tapping of Holding Pot		X	X		
	Casting		X	X		
Secondary Zinc Production	Sweating Furnace Charging/Tapping		X	X		
	Hot Metal Transfer		X			
	Melting Furnace Charging/Tapping		X	X		
	Distillation Retort Charging/Tapping		X	X		
	Distillation Furnace Charging/Tapping		X	X		
	Casting		X	X		

(continued)

TABLE 3-9. (concluded)

Industry	Process source	Control measure				
			Capture/collection			
		Wet suppression[b]	Enclosures[c]	Receiving hoods[d]	Capture hoods	Plume after-treatment
Secondary Copper, Brass/ Bronze Production	Sweating Furnace Charging/Tapping		X	X		
	Dryer Charging/Tapping		X	X		
	Melting Furnace Charging		X	X		
	Casting		X	X		
Ferroalloy Production	Raw Materials Crushing/ Screening	X	X		X	X
	Furnace Charging		X	X	X	
	Furnace Tapping		X	X	X	
	Casting		X	X	X	
Cement Manufacturing	Limestone/Gypsum Crushing and Screening	X	X		X	X
	Coal Grinding	X	X		X	X
Lime Manufacturing	Limestone Crushing/Screening	X	X		X	X
	Lime Screening/Conveying		X		X	X
Rock Products	Primary Crushing/Screening	X	X		X	X
	Secondary Crushing/Screening	X	X		X	X
	Tertiary Crushing Screening	X	X		X	X
Asphalt Concrete Plants	Aggregate Crushing/Screening	X	X		X	X
Coal-Fired Power Plants	Coal Pulverizing/Screening	X	X		X	
Grain Storage and Processing	Grain Cleaning				X	
	Grain Drying				X	
Wood Products	Log Debarking/Sawing		X		X	X
	Veneer Drying		X	X		
	Plywood Cutting		X		X	X
	Plywood Sanding		X		X	X
Mining	Blasting	X				
	Crushing/Screening	X	X		X	X

[a] From Table 4-2 of Reference 13.

[b] Water or water plus chemical additives.

[c] Includes full and/or partial enclosures with possible evacuation to a dust collector.

[d] Most applications involve the use of canopy-type receiving hoods.

TABLE 3-10. FEASIBLE CONTROL MEASURES FOR OPEN DUST SOURCES[a]

Source category	Fugitive emission control measure						
	Enclosures[b]	Wet suppression	Chemical stabilization	Physical stabilization	Vegetative stabilization	Surface cleaning	Capture/removal[c]
Unpaved roads		X	X	X			
Unpaved parking lots and staging areas		X	X	X			
Storage piles	X	X	X	X			
Paved streets and highways						X	
Paved parking lots and staging areas						X	
Exposed areas	X	X	X	X	X		
Batch drop operations[d]	X	X					X
Continuous drop operations[e]	X	X					X
Pushing (e.g., dozing, grading, scraping, etc.)		X	X				

[a] From Table 4-1 of Reference 13.

[b] Includes full and partial enclosures as well as wind fences.

[c] Includes both capture/collection systems and plume aftertreatment.

[d] Includes operations such as front-end loaders, shovels, etc.

[e] Includes operations such as conveyor transfer, stacking/reclaiming, etc.

3.2.4 Performance Data for Process Fugitive Controls

Essentially all of the control techniques used to abate the fugitive emissions associated with process sources utilize traditional engineering approaches.[13] Although performance data are sparse, the application of this technology is generally well developed (with the possible exception of plume aftertreatment). Such is not usually the case for open source controls, as will be discussed below.

Available PM_{10} control efficiency data for water/foam suppression, capture/collection systems, and plume aftertreatment are presented in Tables 3-11, 3-12, and 3-13, respectively.[13] All data shown in these tables were taken directly from Reference 13. Additional information on how the various values were obtained can be found in that document. As shown by these tables, very limited data currently exist on PM_{10} control efficiency for control techniques applicable to process fugitive sources.

It should also be noted that a major portion of the control efficiency data presented in Tables 3-11 to 3-13 have been expressed in terms of respirable dust instead of PM_{10}. Respirable dust is defined as that particulate which passes through a Dorr Oliver 10-mm nylon cyclone attached to a personal sampler operating at a flow rate of 1.7 L/min. The cyclone precollector has a cutpoint which is approximately 10 µmA, although it is not usually expressed as such. Therefore, the control efficiency for respirable dust should closely approximate that for PM_{10} for the source/control combinations listed.

3.2.5 Performance Data for Open Dust Controls

Control techniques applied to open dust sources generally are less durable than traditional control devices applied to ducted sources. It is common practice to assign a single control efficiency value to a baghouse, cyclone, or scrubber. Ducted source controls are generally attributed the capability to maintain a set control efficiency value for extended periods (e.g., 1 or 2 years) given proper maintenance and operation.

discuss control of construction related emissions: prevention of trackout flushing roadway doesn't help much – no specs

TABLE 3-11. SUMMARY OF AVAILABLE PM_{10} CONTROL EFFICIENCY DATA FOR WATER SPRAYS AND FOAM SUPPRESSION (PROCESS SOURCES)[a]

Type of process	Type of material	Process design/ operating parameters	Control system parameters	PM_{10} control efficiency	Comments
Crusher	Gypsum	Not specified	3 Nozzles (2 x 1/32 in. flat), 200 parts H_2O/1 part foaming agent	27%[b]	Efficiency based on concentration only
Secondary crusher	Limestone	424 tons/hr, 3 in. material size	Water spray - not specified	92%	No calibration or wind data available
Tertiary crusher	Limestone	127 tons/hr, 5/8 in. nominal material size	Water spray - not specified	83%	

[a] Reproduced from Table 6-1 of Reference 13. 1 ton = 0.91 Mg; 2.54 cm = 1 in.

[b] Control efficiency for respirable dust which is approximately the same as PM_{10}.

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TABLE 3-12. SUMMARY OF PM_{10} CONTROL EFFICIENCY DATA FOR CAPTURE/COLLECTION SYSTEMS (PROCESS SOURCES)[a]

Type of process	Type of material	Process design/ operating parameters	Capture mechanism/ air pollution control device	Control system parameters	Capture efficiency	Comments
Aluminum reduction cell-anode	Molten aluminum	Not specified	Close capture hood/ NA	Flow = 50 m^3/min	70%	Capture efficiency only; only comparative tracer concentrations; no mass measurements
				Flow = 80 m^3/min	77%	
				Flow = 120 m^3/min	91%	
				Flow = 160 m^3/min	98%	
Aluminum reduction cell tapping	Molten aluminum	Not specified	Close capture/NA	Flow = 120 m^3/min	96%	
Anode removal	Molten aluminum	Not specified	Close capture/NA	Flow = 120 m^3/min	86%	
Banbury mixer	NA	Not specified	Capture hood/NA	Hood 1 m from mixer, cooling fan off	90%	An oil mist aerosol was introduced into the plume at a known rate and quantity in exhaust duct measured
				Hood 1 m from mixer, cooling fan on	40%	
				Hood 3 m from mixer, cooling fan off	70%	

[a] Reproduced from Table 6-3 of Reference 13. No actual control efficiency values are available for sources listed. A tracer gas was used to determine capture efficiency only.

TABLE 3-13. SUMMARY OF AVAILABLE CONTROL PM_{10} EFFICIENCY DATA FOR PLUME AFTERTREATMENT SYSTEMS (PROCESS SOURCES)[a]

Type of process	Type of material	Process design/ operating parameters	Fogger system[b]	Average control efficiency[c]
Bag splitting hood	Cream-tex: 32% alumina 52% SiO_2	Not specified	2-Ransburg REA foggers located inside hood; WFR = 45 cc/min total; AF = 4.3 m^3/hr total	45-61%

[a] Includes only results of field testing. Reproduced from Table 6-4 of Reference 13.

[b] The Ransburg foggers are based on the original Hoenig design which uses induction charging and commercial spray nozzles. WFR = water flow rate. AF = airflow to fogger(s).

[c] Control efficiency for respirable dust which is approximately the same as PM_{10}. Efficiency ranges include average efficiency for both positively/negatively charged fog.

In contrast to ducted source controls, intermittent control techniques which begin to decay in efficiency almost immediately after implementation are often used for open dust sources. The most extreme example of this is the watering of unpaved roads where the efficiency decays from nearly 100% to zero in a matter of hours (or minutes). The control efficiency for broom sweeping and flushing applied in combination on a paved road may decay to zero in 1 or 2 days. Chemical dust suppressants applied to unpaved roads can yield control efficiencies that will decay to zero in several months. Consequently, a single-valued control efficiency is usually not adequate to describe the performance of most intermittent control techniques for open dust sources. The control efficiency must be reported along with a time period over which the value applies. For continuous control systems (e.g., wet suppression for materials transfer), a single control efficiency is usually appropriate.

Certain terminology has been developed to aid in describing the time dependence of control efficiency for intermittent controls for open dust sources. These terms are:

- Control lifetime is the time period (or amount of source activity) required for the efficiency of an open dust control measure to decay to zero.

- Instantaneous control efficiency is the efficiency of an open dust control at a specific point in time.

- Average control efficiency is the efficiency of an open dust source control averaged over a given period of time (or number of vehicle passes).

From the above definitions, it is clear that average control efficiency is related to instantaneous control efficiency by the following general equation:

$$C(T) = \frac{1}{T} \int_{o}^{T} c(t)\ dv \qquad (3\text{-}1)$$

where: C(T) = Average control efficiency during time period T between applications

c(t) = Instantaneous control efficiency at time t after application ($t \leqq T$)

Recent testing of certain unpaved and paved road dust controls suggests that the instantaneous control efficiency can be described with reasonable accuracy as a linear function of vehicle passes (v) as representative of time in the general form:

$$c(v) = 100 - b\ v \qquad (3\text{-}2)$$

where b is the decay rate which is dependent on equipment (e.g., vehicle) or source characteristics, climatic conditions, and control application parameters as will be discussed in detail below. By substituting the linear expression for instantaneous control efficiency into Equation 3-1, the average control efficiency for V vehicle passes can be expressed as follows:

$$C(V) = 100 - \frac{b}{2} V \qquad (3\text{-}3)$$

Typical control techniques employed on open dust sources are listed in Table 3-14. The specifications necessary to completely define each technique are also listed. While most of the terminology is familiar, the terms related to the use of water and chemical dust suppressants need to be defined. Application intensity is the volume of solution placed on a dust-producing surface per unit area or per unit mass of aggregate material handled (e.g., L/m^2, L/Mg). The dilution ratio is defined as volume of chemical mixed with a given volume of water (e.g., 1 L chemical: 7 L water). Application frequency is the number of applications per unit of time (e.g., 6 applications/year, 2 applications/week).

Available PM_{10} control efficiency data for chemical road dust suppressants, unpaved road watering, water sprays, foam suppression systems, and plume aftertreatment are summarized in Tables 3-15 through 3-19, respectively.[13] Again, all data shown in these tables were taken directly from Reference 13. It should be noted that the control efficiency values reported in Table 3-15 are expressed as a least-squares fit of the data based on the number of vehicle passes over the road surface. This is consistent with Equation 3-3 shown above.

TABLE 3-14. OPEN DUST SOURCE CONTROL TECHNIQUE IDENTIFICATION

Generic source category	Control technique	Technique specifications
I. Vehicular travel on unpaved surfaces	1. Wet suppression (watering)	1. Application intensity (L/m^2) 2. Application frequency
	2. Chemical dust suppressants	1. Application intensity 2. Application frequency 3. Dilution ratio (L chemical:L H_2O)
	3. Paving	1. Thickness of asphalt or concrete 2. Base preparation techniques 3. Planned maintenance technique specifications to maintain cleanliness (see technique specifications under paved faces)
II. Vehicular travel on paved surface	1. Vacuum sweeping	1. Application frequency 2. Sweeper characteristics like: a. Capacity of blower b. Air velocity generated along road surface c. Type of device used to remove particles (e.g., bags, water sprays, scrubbers, settling chambers, etc.) d. Characteristics of the gutter broom (e.g., rpm, type of bristle, number of bristles per unit area)
	2. Flushing	1. Application frequency 2. Application intensity
	3. Flushing and broom sweeping	1. Application frequency 2. Application intensity 3. Sweeper speed 4. Characteristics of main and gutter brooms (e.g., rpm, type of bristle, number of bristles per unit area)

(continued)

TABLE 3-14. (concluded)

Generic source category	Control technique	Technique specifications
III. Material handling	1. Enclose transfer stations, conveyors, material stream falling onto pile, etc.	1. Full or partial enclosure 2. Vented or nonvented (full) enclosure 3. If vented to control device, give ventilation rate in acfm.
	2. Spray material on conveyor with surfactant treated water	1. Amount of solution applied (L/Mg) 2. Amount of surfactant added to water (dilution ratio) 3. No. and type of spray nozzles
	*3. Spray material in open storage with water	1. Application intensity (L/m^2) 2. Application frequency
	*4. Spray material in storage with chemical dust suppressant	1. Application intensity (L/m^2) 2. Dilution ratio (vol. chem.:vol. water) 3. Application frequency
	5. Spray plume with electrically-charged fog while material is being dropped	1. Application intensity (L/Mg) 2. Charge-to-mass ratio (C/g) 3. No. of foggers, volume of spray, and volume of plume
	6. Spray while being dropped (e.g., railcar, stacker)	1. Amount of solution applied (L/Mg) 2. No. and type of spray nozzles
	7. Reduce drop distance	1. Exposed drop height before and after control

* These are actually more effective as wind erosion controls rather than material handling controls.

TABLE 3-15. INSTANTANEOUS PM_{10} CONTROL EFFICIENCY FOR UNPAVED ROAD CONTROL TECHNIQUES AS A FUNCTION OF VEHICLE PASSES[19]

Control measure	Time after application	Average No. of vehicle passes per day	Mean vehicle parameters: Weight (Mg)	Mean vehicle parameters: Weight (tons)	Mean vehicle parameters: No. of wheels	Application intensity (L/m^2)	Dilution ratio ($L/L\ H_2O$)	Least-squares fit of PM_{10} control efficiency[a] (%)
Petro Tac-Initial application	2-116 days	410	27	30	9.2	3.2	1:4	102-0.00113 V
Coherex® - initial application	7-41 days	94	34	38	6.2	3.8	1:4	94.9-0.0134 V
Coherex® - reapplication	4-35 days	97	39	43	6.0	4.5	1:7	100-0.00430 V
Watering[b]	1.0-2.8 hr	1,200	44	49	6.0	0.1	N/A	102-0.179 V

[a] V represents cumulative vehicle passes after application. Complete mitigation is assumed immediately after application (i.e., c = 100 @ V = 0).

[b] Run AJ-6 was not used in developing the equations for water.

need to explain

TABLE 3-16. FIELD DATA ON UNPAVED ROAD WATERING CONTROL EFFICIENCY[a]

Location	No. of tests	Month	Applic. intens. (L/m^2)	Avg. time between applic. (hr)	Avg. traf. rate (hr^{-1})	Avg. poten. evap. (mm/hr)	Avg. control eff.[b] (%)
N. Dakota	4	October	0.2	1.8	40	0.084	59
New Mexico	5	July/Aug.	0.2	2.0	23	0.23	69
Ohio	3	November	0.6	4.5	98	0.042	77
Missouri	2	September	1.9	2.8	72	0.26	88

[a] Reproduced from Table 5-3 of Reference 13.

[b] No significant difference in control efficiency as a function of particle size has been observed to date for watering.

How does this data differ from that in Table 3-15.?
Explain how evap. potential calculated. - where one get.
Would like to have equation considering evap pot, / for applic. intensities.
Harman report 5-17

$E = 100 - \frac{0.8\,pdt}{i}$

TABLE 3-17. SUMMARY OF AVAILABLE PM_{10} CONTROL EFFICIENCY DATA FOR WATER SPRAYS (OPEN DUST SOURCES)[a]

Type of process	Type of material	Process design/ operating parameters	Control system parameters	Control efficiency[b]	Comments
Chain feeder to belt transfer	Coal	3 ft drop; 8 tons coal per load	8 Sprays, 2.5 gpm, above belt only	56%	
			8 Sprays, 2.5 gpm + 1 spray on underside of belt	81%	
Belt-to-belt transfer	Coal	Not specified	8 Sprays, 2.5 gpm, above belt only	53%	Control applied at a point 5 transfers upstream
			8 Sprays, 2.5 gpm + 1 spray on underside of belt	42%	Control applied at a point 5 transfers upstream
Grizzly transfer to bucket elevator	Run of mill sand	Not Specified	Liquid vol. 757 mL	46%	
			Liquid vol. 1,324 mL	58%	
			Liquid vol. 1,324 mL[c]	54%	
			Liquid vol. 1,324 mL[d]	54%	
Conveyor transport and transfer	Coal	2 Belts; 0.91 m and 1.07 m widths; ~ 500 m length	3 Spray bars/belt, underside of tail pulley, 5-10 cc H_2O/sec per bar, Delevan "fanjet" sprays	65-75%	Individual test values not specified; no airflow data or QA/QC data

[a] Reproduced from Table 5-8 of Reference 13. 1 ft = 3.28 m; 1 ton = 0.91 Mg; 1 gal. = 3.79 L.

[b] Control efficiency values are for respirable dust which is approximately the same as PM_{10}.

[c] Water + 1.5% surfactant.

[d] Water + 2.5% surfactant.

TABLE 3-18. SUMMARY OF AVAILABLE PM_{10} CONTROL EFFICIENCY DATA FOR FOAM SUPPRESSION SYSTEMS (OPEN DUST SOURCES)[a]

Type of process	Type of material	Process design/ operating parameters	Control system parameters	Control efficiency[b]	Comments
Belt-to-belt transfer	Sand	Sand temp. ~ 120°F	Not specified	19.7%	Efficiency based on concentration only
Belt-to-bin transfer	Sand	Sand temp. ~ 120°F	Not specified	32.7%	Efficiency based on concentration only
Bulk loadout	Sand	Sand temp. ~ 120°F	Not specified	65.3%	Efficiency based on concentration only
Screw-to-belt transfer	Sand	174 tons/hr Sand temp. ~ 190°F	Moisture = 0.25%	10%	Efficiency based on concentration only
Bucket elevator discharge	Sand	179 tons/hr Sand temp. ~ 190°F	Moisture = 0.18%	8%	Efficiency based on concentration only
Belt-to-belt transfer	Sand	193 tons/hr Sand temp. ~ 190°F	Moisture = 0.18%	7%	Efficiency based on concentration only
Feeder bar discharge	Sand	191 tons/hr Sand temp. ~ 190°F	Moisture = 0.19%	2%	Efficiency based on concentration only
Grizzly transfer to bucket elevator	Run of mill sand	Not specified	Foam rate = 10.5 ft³/ton sand Liquid rate = 0.38 gal/min	92%	
			Foam rate = 8.2 ft³/ton sand	74%	
			Liquid rate = 0.34 gal/min		
			Foam rate = 7.5 ft³/ton sand	68%	
			Liquid rate = 0.20 gal/min		

(continued)

TABLE 3-18. (concluded)

Type of process	Type of material	Process design/ operating parameters	Control system parameters	Control efficiency[b]	Comments
Grizzly	Run of mill	Not specified	Foam rate = 4.8 ft^3/ ton sand	0%	
			Liquid rate = 0.18 gal/min		
			Foam rate = 2.6 ft^3/ ton sand	0%	
			Liquid rate = 0.13 gal/min		
			Liquid vol. 1,420 mL	91%	
			Liquid vol. 1,300 mL	73%	
			Liquid vol. 764 mL	68%	
Chain feeder to belt transfer	Coal	3-ft drop, 8 tons coal per load	50 psi H_2O, 2.5% reagent, 4 nozzles 15-20 cfm foam applied	96%	Efficiency based on concentration only
Belt-to-belt transfer	Coal	Not specified	50 psi H_2O, 2.5% reagent, 4 nozzles 15-20 cfm foam applied	71%	Control applied at a point 5 transfers upstream

[a] Reproduced from Table 5-9 of Reference 13. 1 ft^3 = 28.32 m^3; 1 ton = 0.91 Mg; 1 gal. = 3.79 L; 1 Pa = $1.45(10)^{-4}$ psi.

[b] Control efficiency values are for respirable dust which is approximately the same as PM_{10}.

TABLE 3-19. SUMMARY OF AVAILABLE PM_{10} CONTROL EFFICIENCY DATA FOR PLUME AFTERTREATMENT SYSTEMS (OPEN DUST SOURCES)[a]

Type of process	Type of material	Process design/ operating parameters	Fogger system[b]	Average control efficiency[c]
Belt conveyor	Copper concentrate	Not specified	1-Ransburg REA fogger mounted above belt discharge; WFR = 30-60 cc/min AF = not specified	64-77%
Drop box	Copper concentrate	Not specified	1-Ransburg REA fogger in drop box enclosure; WFR = not specified AF = not specified	65.4%
Boxcar unloading	Silica sand	Not specified	4-Ransburg REA foggers located 90° apart around source; WFR = 30 cc/min/fogger AF = not specified	89%
Belt conveyor	Crushed ore	Conveyor width = 1.5 m Belt speed = 152 m/min Ventilation rate = 15-61 m/min	6-Keystone Dynamics Model 109s located 1.5 m above belt (spray concurrent w/direction of belt movement); WFR = 300 cc/min/fogger AF = supply pressure = 344 kPa	0%

[a] Includes only results of field testing. Reproduced from Table 5-10 of Reference 11.

[b] The Ransburg and Keystone foggers are based on the original Hoenig design which uses induction charging and commercial spray nozzles. WFR = water flow rate; AF = airflow to fogger(s).

[c] Control efficiency values for respirable dust which is approximately the same as PM_{10}. Efficiency ranges include average efficiency for both positively/negatively charged fog.

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SECTION 4.0

ESTIMATION OF CONTROL COSTS AND COST EFFECTIVENESS

Development and evaluation of PM_{10} emission control strategies require analyses of the relative costs of alternative control measures. Cost analyses are used by control agency personnel to develop overall strategies for a specific geographical area or to evaluate plant-specific control strategies. Industry personnel perform cost analyses to evaluate control alternatives for a particular source or to develop a plant-wide emissions control strategy. Although the details of these analyses may vary with the objective of the analysis and the availability of cost data, the general format is similar.

The primary goal of any cost analysis is to provide a consistent comparison of the real costs of alternative control measures. The objective of this section is to provide a methodology that will allow such a comparison. It will describe the overall structure of a cost analysis and provide the procedures and resources for conducting the analyses. Sources of cost information and mechanisms for cost updating also are provided.

The approach outlined in this section will focus on cost effectiveness as the primary comparison tool. Cost effectiveness is the ratio of the annualized cost of control to the amount of emissions reduction achieved. Mathematically, cost effectiveness is defined by:

$$C^* = \frac{C_a}{\Delta R} \qquad (4\text{-}1)$$

where: C^* = cost effectiveness (\$/mass of PM_{10} emissions reduction)

C_a = annualized cost of the control measure (\$/year)

ΔR = reduction in annual emissions (PM_{10} mass/year)

This general methodology was chosen because it is applicable equally to different controls that achieve an equivalent emissions reduction on a single source and to controls that achieve varied reductions over multiple sources.

The discussion is divided into four subsections. The first subsection describes general cost analysis methodology including the various types of costs that should be considered and presents methods for calculating those costs. The second subsection identifies the primary cost elements associated with each of the alternative control systems identified in Section 3.0. The third subsection identifies generalized cost estimate procedures (i.e., graphs and tables) for typical control scenarios. The fourth subsection presents example cost calculations for estimating control costs for typical control scenarios.

4.1 GENERAL COST METHODOLOGY

Calculation of cost effectiveness can be accomplished in four steps. First, the alternative control/cost scenarios are selected. Second, the capital costs of each scenario are calculated. Third, the annualized costs for each of the alternatives are developed. Finally, the cost effectiveness is calculated after consideration of the level of emissions reduction.

The general approach for performing each of the four steps is described below. This approach is intended to provide general guidance for cost comparison and should not be viewed as a rigid procedure that must be followed in detail for all analyses. Some elements of the analysis may be omitted by choice or because of resource or informational constraints. However, for comparisons to be valid, these cautions should be observed: (1) all control scenarios should be treated in the same manner; and (2) cost elements that vary radically between cost scenarios should not be omitted.

4.1.1 Select Control/Cost Scenarios

Prior to the cost analysis, general control measures or strategies will have been identified. These measures or strategies will fall into one of the major classes of PM_{10} emission control techniques that were identified in Section 3.0. The first step in the cost analysis is to select a set of specific control/cost scenarios from the general techniques. The specific scenarios will include definition of the major cost elements and identification of specific implementation alternatives for each of the cost elements.

Each of the general control techniques identified in Section 3.0 has several major cost elements, which include capital equipment and operation/maintenance (O&M) items. For example, the major cost elements for chemical stabilization of an unpaved road include: (a) acquiring the chemical; (b) storing the chemical; (c) preparing the road; (d) mixing the chemical with water; and (e) applying the chemical solution. The next step in any cost analysis is definition of these major cost elements. Information is provided in Subsection 4.2 on the major cost elements associated with each of the general techniques defined above.

For each major cost element, several implementation alternatives can be chosen. Options within each cost element include: buying or renting equipment; shipping chemicals by railcar, truck tanker, or in drums via truck; alternative sources of power or other utilities; and use of plant personnel or contractors for construction and maintenance.

4.1.2 Develop Capital Costs

The capital costs of an emissions control system are those direct and indirect expenses incurred up to the date the control system is placed in operation. These capital costs include: actual purchase expenses for capital equipment; labor and utility costs associated with installation of the control system; and system shakedown and start-up costs. In general, direct capital costs are the costs of equipment and auxiliaries and the labor, material, and utilities needed to install the equipment. These costs include system instrumentation and interconnection of the system.

Capital costs also include any cost for site development necessitated by the control system. For example, if a fabric filter on a capture/collection system requires an access road for removal of the collected dust, the access road is included as a capital expense. The types of direct costs typically associated with emissions control systems are included in Table 4-1.

Indirect costs are associated costs incurred by the facility but not directly attributable to specific equipment. Items in this category are[1]:

what other sources used?

1. Engineering costs--include administrative, process, project, and general; design and related functions for specifications; bid analysis; special studies; cost analysis; accounting; reports; purchasing; procurement; travel expenses; living expenses; expediting; inspection; safety; communications; modeling; pilot plant studies; royalty payments during construction; training of plant personnel; field engineering; safety engineering; and consultant services.

2. Construction and field expenses--include costs for temporary field offices; warehouses; craft sheds; fabrication shops; miscellaneous buildings; temporary utilities; temporary sanitary facilities; temporary roads; fences; parking lots; storage areas; field computer services; equipment fuel and lubricants; mobilization and demobilization; field office supplies; telephone and telegraph; time-clock system; field supervision; equipment rental; small tools; equipment repair; scaffolding; and freight.

3. Contractor's fee--includes costs for field-labor payroll; supervision field office; administrative personnel; travel expenses; permits; licenses; taxes; insurance; field overhead; legal liabilities; and labor relations.

4. Shakedown/start-up--includes costs associated with system startup and shakedown.

5. Contingency costs--the excess account set up to deal with uncertainties in the cost estimate including unforeseen escalation in prices, malfunctions, equipment design alterations, and similar over-runs.

The values for these items will vary with the specific operations to be controlled and the types of control systems used. Typical ranges for indirect costs based on the total installed cost of the capital equipment are shown in Table 4-2.

4.1.3 Determine Annualized Costs

A convenient ~~The most common~~ basis for comparison of alternative control systems is by annualized cost. The annualized cost of an emission control system includes operating costs such as labor, materials, utilities, and maintenance as well as the annualized cost of the capital equipment. The annualization of capital costs ~~is a classical engineering economics problem, the solution to which~~ takes into account the fact that money has time value. These annualized costs depend on the interest rate paid on borrowed money or potential interest lost on diverted company money, the useful life of the equipment, and depreciation rates of the equipment.

The components of the annualized cost of implementing a particular control technique are presented in Table 4-3. The operation and maintenance costs reflect increasing frequency of repair as equipment ages, along with increased costs due to inflation for parts, energy, and labor. On the other hand, costs recovered by tax credits or deductions are considered income. Mathematically, the annualized costs of control equipment can be calculated from:

$$C_a = (CRF \times C_p) + C_o + 0.5\, C_o \qquad (4\text{-}2)$$

where:

C_a = annualized costs of control equipment ($/year)

CRF = capital recovery factor (1/year)

C_p = installed capital costs ($)

C_o = direct operating costs ($/year)

0.5 = plant overhead factor

The components of this equation are described below.

The annualized cost of capital equipment is calculated by using a capital recovery factor (CFR). The capital recovery factor combines interest on borrowed funds and depreciation into a single factor. It is a function of the interest rate and the overall life of the capital equipment and can be estimated by the following equation:

$$CRF = \frac{i(1 + i)^n}{(1 + i)^n - 1} \quad (4\text{-}3)$$

where: i = interest rate (annual percent as a fraction)

n = economic life of the control system (years)

The other major components of the annualized cost are operation and maintenance costs (direct operating expenses) and associated plant overhead costs. Operation and maintenance costs elements typically include[1]:

1. Utilities--include water for process use and cooling; steam; and electricity to operate controls, fans, motors, pumps, valves, and lighting.

2. Fuel costs--include the incremental cost of the fuel, where more than the normal supply is used.

3. Raw materials--include any chemicals needed to operate the system.

4. Operating labor--includes supervision and the skilled and unskilled labor needed to operate, monitor, and control the system.

5. Maintenance and repairs--include the manpower and materials to keep the equipment operating efficiently. The function of maintenance is both preventive and corrective, to keep down-time to a minimum.

6. Byproduct costs--in systems producing a salable product, these would be a credit for that product; in systems producing a product for disposal, these would be the costs of disposal.

Another component of the operating cost is overhead, which is a business expense not charged directly to a particular part of the process but is allocated to it. Overhead costs include: administrative, safety, engineering, legal, and medical services; payroll; employee benefits; recreation; and public relations. As suggested by Equation 4-3, these charges are estimated to be approximately 50% of direct operating costs.

4.1.4 Alternative Cost Estimation Procedures

Several methods with varying levels of accuracy are available for estimating the costs of control measures. A brief description of these methods is presented.

4.1.4.1 Detailed Engineering Cost Analysis--

The detailed cost estimate can provide accuracies of plus or minus 5% depending on the level of engineering involved. Detailed estimates take several months of engineering effort to produce process flow sheets, mass and energy balances, plot plans, and equipment citing drawings to provide the basis for subsequent cost analysis. After the package of specifications is established, contractors and equipment manufacturers can proceed with their analyses to provide a quotation for the specified equipment. This level of cost estimation is typically performed after a formal decision has been reached on the most cost-effective control alternative.

4.1.4.2 Study Estimates--

Study cost estimates can provide accuracies of plus or minus 30%. Study estimates can be generally made within a few hours or days depending on the availability of resources and unit cost information. These estimates are produced from a factored method by establishing direct and indirect installation costs that are dependent on known capital equipment costs. The technique used in Capital and Operating Costs of Selected Air Pollution Control Systems is a study estimate[1]. Study estimates are used to help identify the most cost-effective control alternative(s) and specification(s) to begin a detailed engineering cost estimate. Subsection 4.4.1 provides an example study estimate for illustration.

4.1.4.3 Generalized Cost Estimate Procedures--

Generalized cost estimate procedures provide accuracies of plus or minus 50%, resulting in order of magnitude estimate of the anticipated costs. These estimates can be made rapidly by referring to a table, graph, or known cost level for a similar design and a different capacity or scale.

The "six-tenth factor method" is used to adjust mathematically the known cost for a particular system design for another similar system with a different scale. Scaled estimates are calculated by use of the following general equation:

$$C_2 = C_1 \left(\frac{r_2}{r_1}\right)^n \qquad (4\text{-}4)$$

where: C_2 = cost of desired control device

C_1 = cost of known control device

r_2 = capacity of desired control device

r_1 = capacity of known desired control device

$n \cong 0.6$ (can vary from 0.5 to 0.7)

This method consists of using the above equation to relate the primary cost variable with total costs and neglecting the effect of other cost variables. Use of this method should be limited to cases where no other cost information is available.

Another generalized cost estimate procedure is the use of graphs or tables that relate cost values to the primary cost variable. Graphs of this type also provide accuracies of plus or minus 50%.

Section 4.3.1 presents graphs that show the relationship between gas flow rate and estimated costs for the three conventional types of control equipment for ducted sources. The graphs in Section 4.3.1 also depict control costs for the respective secondary cost factor. The secondary cost factors are pressure drop and specific collection area (SCA) for wet scrubbers and electrostatic precipitators (ESP's), respectively. For fabric filters, the secondary cost variable is based on the different design types that are characterized by cleaning method, air-to-cloth ratio, and bag material. Sections 4.3.2 and 4.3.3 present tables with generalized control costs for process fugitive sources and open sources, respectively.

4.2 COST ELEMENTS AND SOURCES OF DATA

4.2.1 Cost Elements

The cost methodology outlined in Section 4.1 requires that the analyst define and select alternative control/cost scenarios and develop costs for the major cost elements within these scenarios. The objective of this section is to identify the implementation alternatives and major cost elements associated with the emission reduction techniques identified in Section 3.0. For ducted sources, the control techniques addressed are wet scrubbers, electrostatic precipitators, and fabric filters. For process fugitive sources, the primary controls discussed are wet suppression, capture/collection, and plume aftertreatment. For open dust sources, the control techniques addressed are wet dust suppression, surface cleaning, and paving.

Control alternatives for ducted sources are presented in Tables 4-4, 4-5, and 4-6 for wet scrubbers, ESP's, and fabric filters, respectively. Process fugitive control alternatives are presented in Tables 4-7 through 4-9. Table 4-7 outlines alternatives for wet suppression systems and Table 4-8 alternatives for a typical capture/collection system. The options shown in Table 4-8 are applicable for active enclosures, capture hoods, and receiving hoods. Table 4-9 presents implementation alternatives for plume aftertreatment systems.

Optional approaches for open dust source control measures are presented in Tables 4-10 through 4-13. Table 4-10 presents implementation alternatives for water and chemical dust suppressant systems for stabilizing unpaved travel surfaces. Table 4-11 presents options for improving paved travel surfaces: sweeping, flushing, and a combination of flushing and broom sweeping. Tables 4-12 and 4-13 present alternatives for wet suppression and paving of streets or parking lots, respectively.

After control scenarios are selected, the analyst must then estimate both the capital cost of the installed system and the operating and maintenance costs. The indirect capital cost elements common to all systems were identified in Table 4-2. The direct capital cost elements and operation and maintenance cost elements, which are unique to each type of PM_{10} emission control system, are identified in Tables 4-14 through 4-22.

Ducted source control cost elements for wet scrubbers, ESP's, and fabric filters are presented in Tables 4-14, 4-15, and 4-16, respectively. Process fugitive control cost elements for wet suppression, capture/collection, and plume aftertreatment are presented in Tables 4-17, 4-18, and 4-19, respectively. Open dust source control cost elements for stabilizing unpaved travel surfaces are presented in Table 4-20; for improving paved travel surfaces, in Table 4-21; and for paving, in Table 4-22.

4.2.2 Sources of Data

Cost estimate procedures and information for ducted source control measures are contained in References 1 through 20. Venturi scrubber cost information is contained in References 1 and 11. Electrostatic precipitator cost information is contained in References 1 and 10. Fabric filter cost information is contained in References 1 and 12. Wastewater treatment cost information is contained in References 18 and 21. Cost information for process fugitive sources and open dust controls are contained in References 20, 21, 22, and 23.

Cost information for updating unit costs are contained in Reference 1, Chemical Engineering issues, Producer Prices and Price Indexes and Employment and Earning Reports published by the U.S. Department of Labor, Bureau of Labor Statistics.

4.3 ~~GENERALIZED~~ COST ESTIMATE PROCEDURES

This subsection presents generalized cost information for quick study estimates (±50%) for the common PM_{10} control measures. Development and evaluation of PM_{10} control strategies require analyses of the relative cost effectiveness of alternative control measures. Quick determination of the cost effectiveness of alternative controls is helpful for screening purposes because the least cost-effective options can be eliminated. Thus, the most cost-effective alternatives can then be studied in detail. Combined use of the generalized cost procedures in this section with the detailed procedures presented in Section 4.2 will provide increased accuracies when needed.

4.3.1 Generalized Cost Estimation for Point Source Control Alternatives

This section presents generalized cost data for three point source control alternatives. Three cost curves representing purchased equipment costs, total capital costs, and annualized costs are given for each type of control. All costs were estimated from information contained in References 1 and 30 and updated to April 1985 dollars.

4.3.1.2 Wet Scrubber Generalized Cost Estimation--

Figure 4-1 shows purchased equipment costs for a venturi scrubber with a combined throat and carbon steel construction for design pressure drops of 20, 40, and 60 in. water column (w.c.). Figures 4-2 and 4-3 present capital and annualized cost for a venturi scrubber with carbon steel and stainless steel construction, respectively, for pressure drops of 20, 40, and 60 in. w.c.

4.3.1.2 ESP Generalized Cost Estimation--

Figures 4-4 shows purchased equipment costs for an insulated ESP with carbon steel construction for four cases: moderate-to-low resistivity dust for total particulate control efficiencies of 99.5 and 99.9%; and high resistivity dust for total particulate control efficiencies of 99.5 and 99.9%. Figure 4-5 shows capital and annualized costs for the four cases.

4.3.1.3 Fabric Filter Generalized Cost Estimation--

Figure 4-6 shows purchased equipment costs for three fabric filter designs: (1) reverse air cleaning with air-to-cloth ratios ranging from 1.5 to 3.3 ft/min with nylon bags; (2) shake cleaning with an air-to-cloth ratios ranging from 2.0 to 3.3 ft/min with nylon bags; and (3) pulse cleaning with an air-to-cloth ratios ranging from 3.3 to 7.0 ft/min with Nomex® bags. Figures 4-7 and 4-8 show capital and annualized costs for fabric filters with stainless steel and carbon steel construction, respectively, for the three cases.

Each of the control system cost curves include the costs of auxiliary equipment normally associated with such a system. In some instances, one may wish to know what the system would cost either with or without the ductwork, fan, and fan drive. The capital and annualized costs of the components are shown in Figures 4-9 and 4-10.

4.3.2 Generalized Cost Estimation for Process and Open Source Fugitive Control Alternatives

Table 4-23 presents typical costs for wet suppression of process fugitive sources and Table 4-24 similar costs for wet suppression of open sources. Cost estimates for stabilization of open sources and improvement of paved travel surfaces are presented in Tables 4-25 and 4-26, respectively.

4.4 EXAMPLE COST ESTIMATE CALCULATIONS

This section presents example calculations for estimating typical control costs of a point source, a process fugitive source, and an open source. The example calculations illustrate the complete procedure for estimating capital costs, operating and maintenance costs, annualized costs, and cost effectiveness.

4.4.1 Typical Ducted Source Control Cost Estimate

The example calculation is based on applying a venturi scrubber with a waste treatment system to control the emissions from a flash dryer in the diatomite processing industry. Tables 4-27 and 4-28 are presented as guidelines and working forms to be used to identify and specify the cost elements to be estimated. Table 4-27 is used to specify the alternatives necessary to estimate the costs of the venturi scrubber to be installed for this example. Table 4-28 is used to identify the scope of cost elements to be estimated. Tables 4-29 and 4-30 present the details, equations, and references for estimating capital costs and annualized costs, respectively, for a typical ducted source.

The costing technique demonstrated by this example (and used in Reference 1) is the factored method of establishing direct and indirect installation costs based on known equipment costs. The resulting cost estimate using this method can provide accuracies of plus or minus 30%. A description of the calculations used to estimate capital and annualized costs and cost effectiveness for the sample case follows.

Capital costs: Estimation of the capital costs for this example case was performed using the factored method (Reference 1), with the exception of the wastewater treatment system (Reference 26) and continuous pressure drop and liquid flow monitoring system (References 27, 28, 29). Table 4-29 presents the capital costs for each component in the venturi scrubber system along with specifications and references.

The control devices and auxiliary equipment items are individually costed from identified graphs and tables contained in Reference 1. Current and appropriate cost factors are identified and used to update the December 1977 cost values (used in Reference 1) to April 1985 cost values. Sources of these cost factors are also included in Table 4-29.

Wastewater treatment costs were obtained from Reference 26 and updated from December 1982 values to April 1985 values. Continuous monitor costs were obtained from vendors and updated from February 1983 values to April 1985 values.

Total annualized costs: Total annualized costs are determined by considering all the component charges for: utilities; operating labor; total maintenance; total overhead; product recovery; and capital charges. Product recovery costs, when applicable, represent a cost savings. Annualized costs are determined by the following equation:

Annualized costs = utility cost + operating labor + total maintenance cost + overhead costs + capital charges - product recovery costs

Substituting appropriate dollar values:

Annualized costs = 487,299 + 31,105 + 27,200 + 44,484 + 365,497 - 0
= $955,565/yr

Cost effectiveness: Cost effectiveness, as discussed previously, is calculated by use of Equation 4-1:

$$C^* = \frac{Ca}{\Delta R}$$

The estimated PM_{10} emission reduction is determined by the following equation:

$$\Delta R = 4.285(10)^{-6}\ CPM_{10} \times Q_{DS} \times H \times E_{10} \qquad (4\text{-}5)$$

where: ΔR = annual reduction in PM_{10} emissions (mass/year);

CPM_{10} = inlet concentration of PM_{10} to control device (gr/dscf);

Q_{DS} = airflow rate to control device (dscf/min);

H = hours of operation (h/yr);

E_{10} = PM_{10} control efficiency;

and $4.285 \times 10^{-6}\ (\frac{\text{min-ton}}{\text{h/gr}})$ = conversion factor.

Substituting appropriate values:

$$\Delta R = (2.8 \frac{gr}{dscf})(26{,}770 \frac{dscf}{min})(8{,}000\ h/yr)(0.95)(4.285 \times 10^{-6} \frac{min\text{-}ton}{h\text{-}gr})$$

$$= 2{,}440\ ton/yr$$

Cost effectiveness for PM_{10} is then calculated by substituting appropriate values:

$$C^* = \frac{Ca}{\Delta R}$$

$$C^* = (\$955{,}585/yr)/(2{,}440\ ton/yr)$$

$$C^* = \$392/ton\ of\ PM_{10}$$

4.4.2 Typical Fugitive Control Cost Estimates

The example calculation is based on controlling PM_{10} emissions by wet suppression at a typical crushing plant. Tables 4-31 and 4-32 are presented as guidelines and working forms to be used to identify and specify the cost elements to be estimated for this example case. Table 4-33 presents detailed calculations and references for typical capital costs, operating costs, annualized costs, and cost effectiveness values.

The example calculation is based on controlling emissions by stabilizing unpaved travel surfaces with a choice of two commercially available dust suppressants. Table 4-34 presents the steps necessary to estimate costs and cost effectiveness. Tables 4-35 through 4-38 contain supplemental information for Table 4-34.

TABLE 4-1. TYPICAL CAPITAL COST ELEMENTS

• Equipment costs	• Painting
• Equipment installation	• Insulation
• Instrumentation	• Structural support
• Duct work	• Foundations
• Piping	• Supporting administrative structures
• Electrical	• Control panels
• Site development	• Access roads or walkways
• Buildings	

TABLE 4-2. TYPICAL VALUES FOR INDIRECT CAPITAL COSTS[1]

Cost item	Range of values
Engineering	8 to 20% of installed cost. High value for small projects; low value for large projects.
Construction and field expenses	7 to 70% of ~~installed cost.~~ purchased equip.
Contractor's fee	10 to 15% of ~~installed cost.~~ purchased equip.
Shakedown/startup	1 to 6% of ~~installed cost.~~ purchased equip.
Contingency	10 to 30% of total direct and indirect costs depending upon accuracy of estimate. Generally, 20 percent is used in a study estimate.

Reference?

TABLE 4-3. TYPICAL ANNUALIZED COST ELEMENTS
(198_ dollars)

Direct operating costs	
Operating labor	
Operator	$12.35/man-hour
Supervisor	15% of operator
Operating materials	As required
Maintenance	
Labor	$13.60/man-hour
Material	Equal to maintenance labor costs
Replacement parts	As required
Utilities	
Electricity	$0.0715/kWh
Fuel oil No. 2	$0.809/gal.
Natural gas	$3.11/MCT
Plant water	$0.60/1,000 gal.
Water treatment	$1.55/1,000 gal.
Steam	NA[a] } Ref 1
Compressed air	NA
Waste disposal	As required Ref 18
Indirect operating costs	
Overhead	80% of operating labor and maintenance labor
Property tax	1% of capital costs
Insurance	1% of capital costs
Administration	2% of capital costs
Capital recovery cost	$[i(1+i)^n] \div [(1+i)^n-1]$, i = annual interest rate, n = effective life; example factor for 13% interest and 10 years equipment life = 0.1843
Credits	
Recovered product	As required

[a] NA = Not available.

TABLE 4-4. ~~CONTROL ALTERNATIVES~~ Design Considerations FOR WET SCRUBBERS

I. Basic design decisions

A. What are the specifications of the gas stream to be controlled?

1. Maximum gas flow rate--actual and dry standard conditions
2. Gas temperature and moisture content
3. Increase in gas flow rate due to evaporative cooling, if any
4. Particulate concentration and size distribution

B. What performance specifications are needed to achieve emission reduction?

1. Collection efficiency
2. Pressure drop
3. Liquid-to-gas ratio
4. Throat adjustment mode (manual or automatic)

C. What materials of construction are required?

1. Metal thickness due to pressure drop and gas flow rate
2. Carbon steel or stainless steel

What is the source of water?

D. What are the waste treatment and disposal requirements?

1. Once through water system/makeup water supplied
2. Chemicals and equipment for treatment
3. Landfill or surface impoundment

E. What are the ~~restraints~~ constraints for retrofit?

1. Space limitations
2. Availability of water and surface impoundment
3. Minimum outage period
4. Availability of electricity

II. Construction/installation decisions

A. Who will install system?

1. Plant personnel
2. Contractor

B. Who is responsible for system shakedown/start-up?

1. Plant environmental staff
2. Plant personnel
3. Contractor

TABLE 4-4. (concluded)

III. Operation/maintenance decisions

A. What instrumentation is needed for reliable operation?

1. Pressure drop meters
2. Liquid flow meters
3. Temperature indicators
4. Recorders and control panel

B. Who will perform routine maintenance?

1. Plant personnel
2. Contractor

C. How will collected particulate be disposed?

1. Returned to process
2. Landfilled
3. Surface impoundment

TABLE 4-5. CONTROL ALTERNATIVES FOR ELECTROSTATIC PRECIPITATORS

I. Basic design considerations

A. What are the specifications of the gas stream to be controlled?

1. Maximum gas flow rate--actual and dry standard conditions
2. Gas temperature and moisture content
3. Resistivity
4. Particulate concentration and size distribution

B. What performance specifications are needed to achieve emission reduction?

1. Collection efficiency
2. Specific collection area
3. Sectionalization
4. Precollector cyclones

C. What materials of construction are required?

1. Carbon or stainless steel
2. Insulated or uninsulated

D. How will collected material be handled?

1. Screw conveyor
2. Pneumatic transport
3. Slurry piping
4. Batch process
5. Need for fugitives control, if any

E. What are the restraints for retrofit?

1. Space
2. Electricity
3. Minimum outage period

II. Construction/installation decisions

A. Who will install system?

1. Plant personnel
2. Contractor

TABLE 4-5. (concluded)

B. Who is responsible for system shakedown/startup?

    1. Plant environmental staff
    2. Plant personnel
    3. Contractor

III. Operation/maintenance decisions

A. What instrumentation is needed for reliable operation?

    1. Primary and secondary voltage and current meters
    2. Indicators for plate and wire rapping
    3. Temperature indicators
    4. Recorders and control panel
    5. Opacity monitor

B. Who will perform routine maintenance?

    1. Plant personnel
    2. Contractor

C. How will collected particulate be disposed?

    1. Returned to process
    2. Landfilled
    3. Surface impoundment

TABLE 4-6. ~~CONTROL ALTERNATIVES~~ Design Considerations FOR FABRIC FILTERS

I. Basic design decisions

A. What are the specifications of the gas stream to be controlled?

1. Maximum gas flow rate--actual and dry standard conditions
2. Gas temperature and moisture content
3. Particulate concentration and size distribution

B. What performance specifications are needed to achieve emission reduction?

1. Collection efficiency
2. Air-to-cloth ratio
3. Type of cleaning mechanism
4. Bag material
5. Flow configuration (pressure or suction)

C. What materials of construction are required?

1. Carbon or stainless steel
2. Insulated or uninsulated

D. How will collected material be handled?

1. Screw conveyor
2. Pneumatic transport
3. Slurry piping
4. Batch process
5. Need for fugitive control, if any

E. What are the restraints for retrofit?

1. Space
2. Minimum outage period

II. Construction/installation decisions

A. Who will install system?

1. Plant personnel
2. Contractor

B. Who is responsible for system shakedown/startup?

1. Plant environmental staff
2. Plant personnel
3. Contractor

TABLE 4-6. (concluded)

III. Operation/maintenance decisions

A. What instrumentation is needed for reliable operation?

1. Bag pressure drop meters
2. Bag cleaning indicators
3. Temperature indicators
4. Recorders and control panel
5. Opacity monitor

B. Who will perform routine maintenance?

1. Plant personnel
2. Contractor

C. How will collected particulate be disposed?

1. Returned to process
2. Landfilled
3. Surface impoundment

D. How frequently will bag replacement occur?

1. As needed
2. Every year
3. Every other year

TABLE 4-7. ~~CONTROL ALTERNATIVES~~ FOR WET SUPPRESSION OF PROCESS FUGITIVES

I. Basic design decisions

  A. What type wet suppression system will be used?

    1. Water spray
    2. Water/surfactant spray
    3. Micron-sized foam
    4. Combination system

  B. What sources will be controlled?

  C. What system layout will be used?

    1. Centralized supply with headers for each source
    2. Individual systems for some sources

II. Construction/installation decisions

  A. Who will install system?

    1. Contractor
    2. Plant personnel

III. Operational decisions

  A. What is the water source?

    1. Plant wells
    2. Local surface waters
    3. City water system

  B. Under what weather conditions will the system be needed?

    1. Above freezing only
    2. Below freezing

  C. How will routine maintenance be provided?

    1. Plant personnel
    2. Maintenance contractor

TABLE 4-8. Design Considerations ~~CONTROL ALTERNATIVES~~ FOR CAPTURE/COLLECTION SYSTEMS

I. Basic design decisions

   A. What type hooding system best fits each source?

      1. Enclosure
      2. Capture hood
      3. Receiving hood

   B. What type of air pollution control device best meets plant needs?

      1. Cyclone
      2. Wet scrubber
      3. Fabric filter

   C. How will collected particulate be handled?

      1. Screw conveyor
      2. Pneumatic transport
      3. Slurry piping
      4. Batch removal

   D. What system layout will be used?

      1. Multiple collection points ducted to centralized air pollution control device
      2. Dedicated air pollution control devices for each source
      3. Mixed system

   E. Who will design the system?

      1. Outside design of total system
      2. Plant design of system with vendor design of individual components

II. Construction/installation

   A. Who will install system?

      1. Plant personnel
      2. Contractor

   B. Who is responsible for system shakedown/start-up?

      1. Plant environmental staff
      2. Plant operators
      3. Contractor personnel

TABLE 4-8. (concluded)

III. Operational decisions (dependent on type of system selected)

A. What electrical source will be used?

1. Public utility
2. Plant power system

B. What water source will be used?

1. Plant well
2. Local surface water
3. Public water system

C. How will routine maintenance be provided?

1. Plant personnel
2. Outside contractor

D. How will collected particulate be disposed?

1. Returned to process
2. Landfilled
3. Surface impoundment

TABLE 4-9. CONTROL ALTERNATIVES FOR PLUME AFTERTREATMENT SYSTEMS

I. Basic design decisions

   A. What sources are to be controlled?

   B. What is the physical size of the source and resulting dust plume?

   C. Is the area sheltered from wind or cross drafts such that aftertreatment can be effectively applied?

   D. How many foggers or nozzles are to be used and where are they to be positioned?

   E. How will water and electric power be supplied to unit(s)?
      1. Central system
      2. Separate line(s) from multiple sources

II. Construction/installation decisions

   A. Who will install system?
      1. Contractor
      2. Plant personnel

III. Operational decisions

   A. What is the water source?
      1. Plant wells
      2. Local surface waters
      3. City water system

   B. What electrical source will be used?
      1. Public utility
      2. Plant power

   C. Under what weather conditions will the system be needed?
      1. Above freezing only
      2. Below freezing

   D. How will routine maintenance be provided?
      1. Plant personnel
      2. Maintenance contractor

TABLE 4-10. CONTROL ALTERNATIVES FOR STABILIZATION OF UNPAVED TRAVEL SURFACES

Program implementation alternative	Dust suppressant type: Chemicals	Dust suppressant type: Water
I. Purchase and ship dust suppressant		
A. Ship in railcar tanker (11,000-22,000 gal/tanker)	x	
B. Ship in truck tanker (4,000-6,000 gal/tanker)	x	
C. Ship in drums via truck (55 gal/drum)	x	
II. Store dust suppressant		
A. Store on plant property		
1. In new storage tank	x	
2. In existing storage tank		
a. Needs refurbishing	x	
b. Needs no refurbishing	x	
3. In railcar tanker		
a. Own railcar	x	
b. Pay demurrage	x	
4. In truck tanker		
a. Own truck	x	
b. Pay demurrage	x	
5. In drums	x	
B. Store in contractor tanks	x	
III. Prepare road		
A. Use plant-owned grader to minimize ruts and low spots	x	x
B. Rent contractor grader	x	x
C. Perform no road preparation	x	x
IV. Mix dust suppressant/water in application truck		
A. Put suppressant in spray truck		
1. Pump suppressant from storage tank or drums into application truck	x	
2. Pour suppressant from drums into application truck, generally using forklift	x	
B. Put water in application truck		
1. Pump from river or lake	x	x
2. Take from city water line	x	x
V. Apply suppressant solution via surface spraying		
A. Use plant owned application truck	x	x
B. Rent contractor application truck	x	x

TABLE 4-11. CONTROL ALTERNATIVES FOR IMPROVEMENT OF PAVED TRAVEL SURFACES

Program implementation alternative	Control alternatives: Broom-sweeping	Flushing	Flushing and broom-sweeping
I. Acquire flusher and driver			
A. Purchase flusher and use plant driver	x ?	x	x
B. Rent flusher and driver		x	x
C. Use existing unpaved road watering truck		x	x
II. Acquire broom sweeper and driver			
A. Purchase broom sweeper and use plant driver	x		x
B. Rent broom sweeper and driver	x		x
III. Fill flusher tank with water			
A. Pump water from river or lake		x	x
B. Take water from city line		x	x
IV. Maintain purchased flusher		x	x
V. Maintain purchased broom sweeper	x		x

TABLE 4-12. CONTROL ALTERNATIVES FOR WET SUPPRESSION OF UNPAVED SURFACES

Program implementation alternatives
I. Prepare road
A. Use plant owned grader to minimize ruts and low spots
B. Rent contractor grader
II. Put water into application truck
A. Pump from river or lake
B. Take from city water
III. Apply water via surface spraying
A. Use plant owned application truck
B. Rent contractor application truck

TABLE 4-13. CONTROL ALTERNATIVES FOR PAVING

Program implementation alternative
I. Excavate existing surface to make way for base and surface courses
A. 2-in. depth
B. 4-in. depth
C. 6-in. depth
II. Fine grade and compact subgrade
III. Lay and compact crushed stone base course
A. 2-in. depth
B. 4-in. depth
C. 6-in. depth
IV. Lay and compact hot mix asphalt surface course (probably AC120-150)
A. 2-in. depth
B. 4-in. depth
C. 6-in. depth

TABLE 4-14. CAPITAL EQUIPMENT AND O&M EXPENDITURE ITEMS FOR WET SCRUBBERS

Capital Equipment

Scrubber
Separator
Quencher (precooler)
Radial tip fan
Fan motor

Motor starter
Fan damper(s)
Motor drive ← ductwork
Duct insulation

Slurry pump
Sump pump
Instrumentation and control panel
wastewater treatment (if applicable)

O&M Expenditures

Utilities
Water
Electricity

Materials
Chemicals
Spare parts
wastewater treatment
sludge disposal

Labor
Operators
Maintenance
Supervision

TABLE 4-15. CAPITAL EQUIPMENT AND O&M EXPENDITURE ITEMS FOR ELECTROSTATIC PRECIPITATORS

Capital Equipment

Electrostatic precipitator
Precollector cyclone
Fan--backwardly curved blades
Fan motor
Motor starter

Fan damper(s)
Motor drive
Duct
Insulation
Instrumentation and control panel

Ash handling/removal
Hopper heaters

O&M Expenditures

Utilities
Electricity

Materials
Spare parts
dust disposal cost/recovery credit

Labor
Operators
Maintenance
Supervision

TABLE 4-16. CAPITAL EQUIPMENT AND O&M EXPENDITURE ITEMS FOR FABRIC FILTERS

Capital Equipment	
	Fabric filter
	Fan--backwardly curved blades
	Fan motor
	Motor starter
	Motor drive
	Fan damper(s)
	Duct
	Insulation
	Ash handling/removal
	Instrumentation and control panel
O&M Expenditures	
	Utilities
	Electricity
	Compressed air
	Materials
	Spare parts
	Replacement bags
	Labor
	Operators
	Maintenance
	Supervision

TABLE 4-17. CAPITAL EQUIPMENT AND O&M EXPENDITURE ITEMS FOR WET SUPPRESSION OF PROCESS FUGITIVE EMISSIONS

Capital Equipment

- Water spray systems
  - Supply pumps
  - Nozzles
  - Piping (including winterization)
  - Control system
  - Filtering units

- Water/surfactant and foam systems only
  - Air compressor
  - Mixing tank
  - Metering or proportioning unit
  - Surfactant storage area

O&M Expenditures

- Utility costs
  - Water
  - Electricity

- Supplies
  - Surfactant
  - Screens

- Labor
  - Maintenance
  - Operation

TABLE 4-18. CAPITAL EQUIPMENT AND O&M EXPENDITURE ITEMS FOR CAPTURE/COLLECTION SYSTEMS[a]

Capital Equipment

- Dust collector
  - Fabric filter or scrubber
  - Concrete work
  - Dust removal system
  - Control instrumentation
  - Monitoring instrumentation

- Hood(s) or enclosure(s)

- Ventilation system
  - Fan
  - Electrical wiring
  - Ductwork
  - Concrete support work
  - Damper system
  - Expansion joints

- Dust storage system

O&M Expenditures

- Utilities
  - Electricity
  - Water

- Supplies
  - Replacement bags
  - Fan motors
  - Chemical additives for scrubber

- Labor
  - System operation
  - Control device maintenance and cleaning
  - Ductwork maintenance

- Disposal of collected particulate

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[a] Specific items included will depend on the control scenario selected.

TABLE 4-19. CAPITAL AND O&M EXPENDITURES FOR PLUME AFTERTREATMENT SYSTEMS

<u>Capital Equipment</u>

- Fogging or spray heads (nonelectrostatic)
  - Atomizers
  - Supply pumps
  - Plumbing (including weatherization)
  - Water filters
  - Flow control system
- Electrostatic foggers or spray nozzles
  - Atomizer(s) and high voltage power supply
  - Water pumps and plumbing (including weatherization)
  - Water filters
  - Flow control system
  - Power lines and electric utilities

<u>O&M Expenditures</u>

- Utility costs
  - Water
  - Electricity
- Supplies
  - Antifreeze agent(s)
  - Screens
  - Replacement electrodes (if applicable)
- Labor
  - Operation
  - Maintenance

TABLE 4-20. CAPITAL EQUIPMENT AND O&M EXPENDITURE ITEMS FOR CHEMICAL STABILIZATION OF UNPAVED TRAVEL SURFACES[a]

<u>Capital Equipment</u>

- Storage equipment
  - Tanks
  - Railcar
  - Pumps
  - Piping
- Application equipment
  - Trucks
  - Spray system
  - Piping (including winterizing)

<u>O&M Expenditures</u>

- Utility or fuel costs
  - Water
  - Electricity
  - Gasoline or diesel fuel
- Supplies
  - Chemicals
  - Repair parts
- Labor
  - Application time
  - Road conditioning
  - System maintenance

[a] Not all items are necessary for all systems. Specific items are dependent on the control scenario selected.

TABLE 4-21. CAPITAL EQUIPMENT AND O&M EXPENDITURE ITEMS FOR IMPROVEMENT OF PAVED TRAVEL SURFACES

Capital Equipment

- Sweeping
  - Broom
  - Vacuum system
- Flushing
  - Piping
  - Flushing truck
  - Water pumps

O&M Expenditures

- Utility and fuel costs
  - Water
  - Gasoline or diesel fuel
- Supplies
  - Replacement brushes
- Labor
  - Sweeping or flushing operation
  - Truck maintenance
- Waste disposal

TABLE 4-22. CAPITAL EQUIPMENT AND O&M EXPENDITURE ITEMS FOR PAVING

Capital Equipment

- Operating equipment
  - Graders
  - Paving application equipment ← would contract this job!
  - Materials
  - Paving material (asphalt or concrete)
  - Base material

O&M Expenditures

- Supplies
  - Patching material yes
- Labor
  - ~~Surface preparation~~
  - ~~Paving~~
  - Road maintenance yes + sweeping, flushing
  - Equipment maintenance

TABLE 4-23. TYPICAL COSTS FOR WET SUPPRESSION OF PROCESS FUGITIVE SOURCES[a]

Source method	Initial cost (April 1985 dollars)[b]	Unit operating cost (April 1985 dollars[b])
Railcar unloading station (foam spray)	48,700	NR
Railcar unloading station (charged fog)	168,000	NR
Conveyor transfer point (foam spray)	23,700	0.02 to 0.05/ton material treated
Conveyor transfer point (charged fog)	19,800	NR

[a] Reference 20. NR = Not reported.

[b] January 1980 costs updated to April 1985 cost by Chemical Engineering Index. Factor = 1.315.

[c] Based on use of 16 large devices at $10,500 each.

[d] Based on use of three small devices at $6,600 each.

TABLE 4-24. TYPICAL COSTS FOR WET SUPPRESSION OF OPEN SOURCES[a]

Source method	Initial capital cost (April 1985 dollars)[b]	Annual operating cost (April 1985 dollars)[b]
Unpaved road-regular watering	17,100/truck	32,900/truck
Storage pile-regular watering	18,400/system	NR
Exposed area-watering	1,053/acre	25-67/acre

a Reference 20. NR = Not reported.

b January 1980 costs updated to April 1985 cost by Chemical Engineering Index. Factor = 1.315.

TABLE 4-25. SELECTED COST ESTIMATES FOR STABILIZATION OF OPEN DUST SOURCES[a]

Source/control method	Initial capital cost (April 1985 dollars)[b]	Annual operating cost (April 1985 dollars)[b]
Unpaved road-chemicals (lignin or coherex)	7,800-19,700/mile	7,800-19,700/mile
Unpaved road-asphaltic paving	44,700-80,200/mile	6,600-11,900/mile[c]
Exposed areas-chemicals	1,060/acre	40-80/acre
Exposed areas-asphalt paving	15,700/acre	NR
Storage piles-surface crusting chemicals	18,400/system	0.006-0.01/ft^2
Exposed areas-vegegation	200-790/acre	NR[d]

[a] Reference 20. NR = Not reported.

[b] January 1980 costs updated to April 1985 cost by Chemical Engineering Index. Factor = 1.315.

[c] Based on resurfacing every 5 years and 15% opportunity costs.

[d] Dependent on type of vegegation planted, condition of soil, and climate.

TABLE 4-26. COST ESTIMATES FOR IMPROVEMENT OF PAVED TRAVEL SURFACES

Source/control method	Initial capital cost (April 1985 dollars)[a]	Annual operating cost (April 1985 dollars)[a,b]
Paved road-sweeping	6,580-19,700/truck	27,600/truck
Paved road-vacuuming	36,800/truck	34,200/truck
Paved road-flushing	18,400/truck	27,600/truck

[a] January 1980 costs updated to April 1985 cost by Chemical Engineering Index Factor = 1.315. Reference 20.

[b] Cost per mile depends on nature of process and the site.

TABLE 4-27. EXAMPLE CALCULATION CASE: CONTROL COST ALTERNATIVES FOR WET SCRUBBER ON DUCTED SOURCES

I. Basic design decisions

A. What are the specifications of the gas stream to be controlled?

1. Maximum gas flow rate--40,000 acfm; 26,800 dscfm
2. Gas temperature and moisture content--250°F; 10% H_2O
3. Increase in gas flow rate due to evaporative cooling--none
4. Particulate concentration and size distribution--4.0 gr/dscf, total particulate; estimated PM_{10} concentration = 2.8 gr/dscf

B. What performance specifications are needed to achieve emission reduction?

1. Efficiency--99.38 percent, total particulate; 95 percent, PM_{10}, estimated
2. Pressure drop--14 in. w.c. estimated
3. Liquid-to-gas ratio--10 gpm/1,000 acfm

C. What materials of construction are required?

1. Metal thickness due to pressure drop--3/16 in.
2. Carbon steel or stainless steel--carbon steel

D. What are the wastewater treatment and disposal requirements?

1. Chemicals and equipment for treatment--centralized system
2. Return to process--no
3. Landfill--yes
4. Surface impoundment--no

E. What are the restraints for retrofit?

1. Space limitations--none
2. Availability of water and surface impoundment--none
3. Minimum outage period--none

II. Construction/installation decisions

A. Who will install system?

1. Plant personnel--no
2. Contractor--yes
3. Overtime--no

TABLE 4-27. (concluded)

B. Who is responsible for system shakedown/start-up?

1. Plant environmental staff--no
2. Plant personnel--no
3. Contractor--yes

III. Operation/maintenance decisions

A. What instrumentation is needed for reliable operation

1. Pressure drop meters--yes
2. Liquid fow meters--yes
3. Temperature indicators--yes
4. Recorders and control panel--yes

B. How will routine maintenance be performed?

1. Plant personnel--yes
2. Contractor--no

TABLE 4-28. EXAMPLE CALCULATION CASE: CAPITAL EQUIPMENT AND O&M EXPENDITURE ITEMS FOR A WET SCRUBBER ON A TYPICAL DUCTED SOURCE

<u>Capital Equipment</u>	
Scrubber	Venturi
Separator	Included with venturi
Quencher (precooler)	Not needed
Radial tip fan	Yes
Fan motor	Dip proof
Motor starter	Included
Fan damper(s)	Included
Motor drive	Included
Duct insulation	Not needed
Scrubber pump	Included with venturi
Sump pump and motor	Included with venturi
Instrumentation and control panel	Included with venturi
Clarifier	Included in water treatment system
Vacuum filter	Included in water treatment system
<u>O&M Expenditures</u>	
Utilities	
Water	Make up water
Electricity	Yes
Materials	
Chemicals	Yes
Spare parts	Yes
Labor	
Operators	Yes
Supervision	Yes
Maintenance	Yes

TABLE 4-29. EXAMPLE CALCULATION CASE: CAPITAL COSTS FOR A WET SCRUBBER ON A TYPICAL DUCTED SOURCE

Component	Specifications	Capital cost ($) Dec. 1977	Capital cost ($) April 1985	Reference[a]
Control device				
Venturi scrubber	Includes venturi, separator, pumps, and controls; carbon steel, 14 in. WP, 3/16 in. thickness, 1.3 adjustment factor	28,700	42,650	5-13, 5-14
Automatic variable	--	6,350	9,435	5-13
Total	Update factor:[b] 336.2 ÷ 2,262 = 1.486	35,050	52,085	
Auxiliary equipment				
Ductwork	Carbon steel 50 fet., 1/8" in. 2 elbows	3,851	5,722	4-16, 4-17 4-19, 4-22
Radial tip fan BLS Code 1147[c]	38,000 acfm, static pressure = 16.4 Update factor: 358.9 ÷ 234.4 = 1.531	8,800	13,474	4-60, 4-63 4-61
Fan motor BLS Code 11730/403.99[c]	150 hp, 600 rpm-motor Update factor: 334.5 ÷ 216.3 = 1.593 x 110.5 = 1.760	10,000	17,600	4-62, 4-68,
Magnetic starter BLS Code 11750.781.05[c]	With circuit breaker, 150 hp Update factor: 254.1 ÷ 176.3 = 1.441	1,450	2,089	4-61
V-belt drive5 BLS Code 1145[c]	Standard Update factor: 337.6 ÷ 213.7 = 1.580	573	905	4-66
Fan outlet damper CE Index	27,000 dscfm, 16.4 in. static pressure Update factor: 1.486	825	1,226	4-65
Total			41,016	
Wastewater treatment	Clarifier, vacuum filter, and controls		580,000[d]	26

use diff. approach
change system $x/gal

TABLE 4-29. (continued)

Component	Specifications	Capital cost ($) Dec. 1977	April 1985	Reference[a]
Continuous monitors				
--flow meter	Impeller, sensor, display, output transmitter		740[e]	Quote from vendor
--pressure drop sensor	With transmitter		740[e]	Quote from vendor
--chart/vendor	Two per recorder		1,420[e]	Quote from
CE Index[b]	Update factor: 336.2 ÷ 327.6 = 1.026	2,900	2,976	vendor
Total		--	5,876	
TOTAL EQUIPMENT COSTS	Control device, auxiliary equipment, wastewater treatment, and continuous monitors		678,977	3-11
Purchased equipment costs	Instruments and controls (10 percent), taxes (3 percent), freight (5 percent); total (18 percent); multiplier factor = 0.18		122,216	3-11
Installation--direct costs	Foundations and supports (4 percent), erection and handling (50 percent), electrical (8 percent), piping (1 percent), insulation (2 percent), and painting (2 percent); total (67 percent); multiplier factor = 0.67		454,915	3-11

TABLE 4-29. (concluded)

Component	Specifications	Capital cost ($) Dec. 1977	April 1985	Reference[a]
Continuous monitors (continued)				
Installation indirect cost	Engineering and supervision (20 percent), construction and field expenses (20 percent), construction fee (10 percent), start-up (1 percent), performance test (1 percent), contingencies (3 percent); total (55 percent); multiplier factor = 0.55		373,437	3-11
Total capital costs			1,629,500 (rounded)	

[a] All numbers indicate page numbers in Reference 1, except where noted otherwise.

[b] Chemical Engineering Fabricated Equipment Index: April 1985 Index ' December 1977 index = update factor.

[c] Bureau of Labor Statistics Index; April 1985 Index; December 1977 index = update factor.

[d] Value prorated for 40 percent of total system costs; referenced installed cost converted to capital cost; December 1982 costs updated to April 1985 costs by Chemical Engineering Index.

[e] Vendor quote obtained in February 1983; updated to April 1985 costs by C.E. index.

TABLE 4-30. EXAMPLE CALCULATION CASE: ANNUALIZED COSTS AND COST-EFFECTIVENESS FOR A WET SCRUBBER ON A TYPICAL DUCTED SOURCE

Component	Specifications	Annualized cost April 1985 ($)	Reference[a]
Capital costs			
--Sump pump	10 hp, 8,000 hr/yr	4,267	3-17
--Makeup water cost	0.50 gal/1,000 gal., $0.60/1,000 gal.	58	Estimate
--Water treatment	$2.16/1,000 gal., 400 gpm	414,700	
		487,299	
Operating labor costs			
--Operating labor	2 hr/shift, $12.35/hr	24,700	3-14
--Supervisory labor	15% of operating labor	3,705	3-12
		31,105	
Maintenance cost			
--Maintenance labor	1 hr/shift, $13.60/hr	13,600	3-14, 3-12
--Materials	Equal to maintenance labor costs	13,600	3-12
		27,200	
Overhead	80% of total O&M costs	44,484	3-12

electricity ?

TABLE 4-30. (concluded)

Component	Specifications	Annualized cost April 1985 ($)	Reference[a]
Capital charges			
--Administrative costs	2% of capital costs	32,590	3-12
--Property costs	1% of capital costs	16,295	3-12
--Insurance	1% of capital costs	16,295	3-12
--Capital recovery	10 yr, 13% interest, CFR = 0.1843	300,317	3-12
		365,497	
Total annualized costs	Utilities, operating labor, total maintenance, overhead, and capital charges	955,585	3-11
Total annualized costs, (rounded)		955,600	

COST EFFECTIVENESS

Calculated emission reduction =

$$(2.8 \text{ gr/dscf})(26{,}770 \text{ dscf/min})(8{,}000 \text{ h/yr})(0.95)\left(4.285 \times 10^{-6} \frac{\text{min-ton}}{\text{hr-gr}}\right) = 2{,}440 \text{ tons/yr}$$

Cost effectiveness = $955,600 yr/2,440 ton/yr = $392/ton of particulate.

[a] All numbers indicate page numbers in Reference 1.

TABLE 4-31. EXAMPLE CALCULATION CASE: CONTROL COST ALTERNATIVES FOR WET SUPPRESSION OF PROCESS FUGITIVE EMISSIONS

I. Basic design decisions

A. What type wet suppression system will be used?

1. Water spray--yes
2. Water/surfactant spray--no
3. Micron-sized foam--no
4. Combination systm--no

B. What sources will be controlled? One primary, one secondary, and one tertiary crusher; truck dump to primary crusher, two screens, and six conveyor transfer points

C. What system layout will be used?

1. Centralized supply with headers for each source--yes
2. Individual systems for some sources
   Note: process operates 40 hr/week, 48 week/yr, totaling 1,920 hr/yr; controls operate 80% of process time, or 1,536 hr/yr

II. Construction/installation decisions

A. Who will install system?

1. Contractor--yes
2. Plant personnel--no

III. Operational decisions

A. What is the water source?

1. Plant wells--yes
2. Local surface waters--no
3. City water system--no

B. Under what weather conditions will the system be needed?

1. Above freezing only--no
2. Below freezing--yes, requires winterization

C. How will routine maintenance be provided?

1. Plant personnel--yes
2. Maintenance contractor--no

TABLE 4-32. EXAMPLE CALCULATION CASE: CAPITAL EQUIPMENT AND O&M EXPENDITURE ITEMS FOR WET SUPPRESSION OF PROCESS FUGITIVE EMISSIONS

Capital Equipment

- Water spray systems
  - Supply pumps--yes
  - Nozzles--yes
  - Piping (including winterization)--yes
  - Control system--yes
  - Filtering units--yes

- Water/surfactant and foam systems only
  - Air compressor--yes
  - Mixing tank--yes
  - Metering or proportioning unit--yes
  - Surfactant storage area--yes

O&M Expenditures

- Utility costs
  - Water--yes, $/1,000 gal.
  - Electricity--yes, $/kWh

- Supplies
  - Surfactant--yes
  - Screens--no

- Labor
  - Maintenance--192 hr/yr
  - Operation--96 hr/yr

TABLE 4-33. EXAMPLE CALCULATION CASE: COST ESTIMATION FOR PROCESS FUGITIVE CONTROL

Type of equipment	Equipment cost ($)	Installation cost ($)	Total cost ($)
CAPITAL COSTS[a,b]			
Wet suppression system	24,520	33,830	58,350
Water filter and flush	2,970	350	3,320
High pressure system for truck dump	4,630	2,290	6,920
Shelter house	4,280	640	4,920
Winterization[c]	3,640	3,710	7,350
Total	40,040	40,820	80,860

Component	Annualized cost ($)
ANNUAL OPERATING COSTS	
Utilities	
Electrical power - 2,880 kWh/yr @ 5.5¢/kWh[d] (Table 4-3 0.0715/kwh)	160
Water - 690,000 gal/yr @ $0.60/ 1,000 gal.[e]	410
Maintenance (Table 4-3 ?)	
Labor - 192 hr/yr @ $10/hr[f]	1,920
Materials	1,850
Operation	
Labor - 96 hr/yr at $10/hr[f]	960
Surfactant 690 gal/yr @ $6/gal.[g]	4,140
Overhead	
Payroll (35% of labor)	1,010
Office/general (40% of maintenance and operations)	3,620
Capital recovery	
10 yr, 15% interest, CR = 0.1992	16,107
Total operating cost (rounded)	30,180

TABLE 4-33. (concluded)

COST EFFECTIVENESS

Operating rate: 300 ton/hr
Operating hours: 1,920 hr/yr
Utilization: 80%

} 576,000 T/yr

Calculated emissions reductions

Primary crusher:	(29 ton/yr)(0.80)	= 23
Secondary crusher:	(173 ton/yr)(0.65)	= 112
Tertiary crusher:	(864 ton/yr)(0.5)	= 432
Screens:	(190 ton/yr)(0.5)	= 95

Total = 662 ton/yr

$$\text{Cost effectiveness} = \frac{\$30,180/\text{yr}}{662\ \text{ton/yr}} = \$46/\text{ton of particulate}$$

$$\frac{\$30,180/\text{yr}}{576,000\ \text{T/yr}} = \$.052/\text{T material processed}$$ Bill?

[a] Reference for capital costs and units of operating materials, utilities, and labor: Evans, R. J., Methods and Costs of Dust Control in Stone Crushing Operations, PB-240 834, U.S. Bureau of Mines, IC 8669, January 1975.

[b] Costs are updated from July 1974 to January 1984 using the CE Plant Cost Index for Fabricated Equipment.

[c] Estimated as 10% of other capital equipment.

[d] Estimated average cost of electrical power for industrial users as of January 1984 based on Energy Users.

[e] MRI estimate.

[f] Estimated hourly rate for a laborer in the minerals manufacturing industry in January 1984 based on statistics in the Monthly Labor Review.

[g] Costs updated from July 1974 to January 1984 using CE Plant Cost Index for Pipes, Valves, and Fittings.

TABLE 4-34. EXAMPLE CALCULATION CASE: COST AND COST EFFECTIVENESS ESTIMATE FOR TYPICAL OPEN SOURCE CONTROL

This table lists the steps necessary to calculate the cost effectiveness for two control alternatives for stabilizing unpaved travel surfaces. Following the list of nine steps is an example problem illustrating the calculations. Table 4-35 through 4-38 are referenced in the calculations in Table 4-34.

Step 1 - Specify Desired Average Control Efficiency (e.g., 50, 75, or 90%)

Step 2 - Specify Basic Vehicle, Road and Climatological Parameters for the Particular Road of Concern

Required vehicle characteristics include:

1. Average Daily Traffic (ADT)-This is the number of vehicles using the road regardless of direction of travel (e.g., on a two lane road in an iron and steel plant, 100 vehicles in one direction, and 100 in the other direction during a single day yields 200 ADT);
2. Average vehicle weight in short tons;
3. Average number of vehicle wheels; and
4. Average vehicle speed in mph.

Required road characteristics include:

1. Actual length of roadway to be controlled in miles;
2. Width of road to be controlled;
3. Silt content (in percent)-For an existing road, these values should be measured; however, for a proposed plant, average values shown in ~~AP-42~~ Tables 2-1 2-2 or AP-42 can be used;
4. Surface loading (for paved roads) in lb/mile - This is the total loading on all traveled lanes rather than the average lane loading; and
5. Bearing strength of the road-At this time, just a visual estimate of low, moderate, or high is required.

Required climatological characteristics (applicable only to watering of unpaved roads): Potential evaporation in mm/hr--the value depends on both the location and the month of concern. Control efficiency data in this report for watering unpaved roads assume a location in Detroit, Michigan, in the summer.

Step 3 - Calculate the Uncontrolled Annual Emission Rate as the Product of the Emission Factor and the Source Extent

The emission factor (E) should be calculated using the equations from ~~AP-42~~ chapter 2,

TABLE 4-34. (continued)

The annual source extent (SE) is calculated as 365 x ADT x average one way trip distance.

Step 4 - Consult the Appropriate Control Program Design Table to Determine the Time Between Applications and the Application Intensity

Select the appropriate table

Control technique	Table containing information
Coherex® applied to unpaved roads	Table 4-35
Petro Tac applied to unpaved roads	Table 4-26

Verify that the vehicle and road characteristics listed in Step 2 are similar to those listed in the footnotes of the selected table. If they are significantly different, the table cannot be used.

Step 5 - Calculate the Number of Annual Applications Necessary by Dividing 365 by the Days Between Application (from Step 4)

Step 6 - Calculate the Number of Treated Miles Per Year by Multiplying the Actual Miles of Road to be Controlled (from Step 2) by the Number of Annual Applications (from Step 5)

Step 7 - Consult the Appropriate Program Implementation Alternatives Table and Select the Desired Program Implementation Plan

Control technique	Table containing information
Coherex® applied to unpaved roads	Table 4-37
Petro Tac applied to unpaved roads	Table 4-38

Step 8 - Calculate Total Annual Cost by Annualizing Capital Costs and Adding to Annual Operation and Maintenance Costs

To annualize capital investment, the capital cost is multiplied by a capital recovery factor which is calculated as follows:

$$CRF = [i(1 + i)^n] / [(1 + i)^n - 1]$$

where

CRF = capital recovery factor

i = annual interest rate fraction

n = number of payment years

Scale total annual cost by ratio of actual road width in feet divided by 40 ft.

Step 9 - Calculate Cost Effectiveness by Dividing Total Annual Costs (from Step 8) by the Annual Uncontrolled Emission Rate (from Step 3) and by Desired Control Efficiency Fraction (from Step 1)

Example calculation. The following is an example cost-effectiveness calculation for controlling PM-10 using Coherex® on an unpaved road in a Detroit, Michigan, plant.

Step 1 - Specify Desired Average Control Efficiency
Desired average control efficiency = 90%

Step 2 - Specify Basic Vehicle, Road, and Climatological Parameters for the Particular Road of Concern

Required vehicle characteristics:
1. Average daily traffic = 100 vehicles per day;
2. Average vehicle weight = 40 ST;
3. Average number of vehicle wheels = 6; and
4. Average vehicle speed = 20 mph

Required road characteristics
1. Actual length of roadway to be controlled = 6.3 miles;
2. Width of roadway = 30 ft;
3. Silt content = 7.3%
4. Bearing strength of road = moderate

Step 3 - Calculate Uncontrolled Annual Emission Rate as the Product of the Emission Factor and the Source Extent

$$E = k\ 5.9\ \frac{s}{12}\ \frac{S}{30}\left(\frac{W}{3}\right)^{0.7}\left(\frac{w}{4}\right)^{0.5}\frac{365-p}{365}$$

E = emission factor
k = 0.45 for PM-10 (as per Appendix C)
s = 7.3 percent (given in Step 2)
S = 20 mph (given in Step 2)
W = 40 ST (given in Step 2)
w = 6 (given in Step 2)
p = 140 (as per Figure 11.2-1-1 in Ap-42 Supplement 14 for Detroit, Michigan)

TABLE 4-34. (continued)

$E = 4.98$ lb/VMT

SE = 365 x ADT x average one-way trip distance

$$SE = 365 \frac{\text{days}}{\text{year}} \times 100 \frac{\text{vehicles}}{\text{day}} \times \frac{6.3}{2} \frac{\text{miles}}{\text{vehicle}}$$

SE = 115,000 VMT/year

Emission rate = E x SE

$$\text{Emission rate} = 4.98 \text{ lb/VMT} \times 115{,}000 \text{ VMT/year} \times \frac{1}{2{,}000} \frac{\text{short ton}}{\text{lb}}$$

Emission rate = 286 tons of PM_{10} per year

Step 4 - Consult the Appropriate Control Program Design Table To Determine the Times Between Applications and the Application Intensity

Use Table 4-35.

The vehicle and road characteristics listed in Step 2 are similar to those in the footnotes of Table 2-1.

From Table 4-35:

Application intensity = 0.83 gal. of 20% solution/yd^2 (initial application)

= 1.0 gal. of 12% solution/yd^2 (reapplications)

Application frequency = once every 47 days

Step 5 - Calculate the Number of Annual Applications Necessary by Dividing 365 by the Days Between Applications (from Step 4)

$$\text{No. of annual applications} = \frac{365}{47} = 7.77 \frac{\text{applications}}{\text{year}}$$

Step 6 - Calculate the Number of Treated Miles Per Year by Multiplying the Actual Miles of Road to Be Controlled (from Step 2) by the Number of Annual Applications (from Step 5)

$$\text{No. of treated miles per year} = 6.3 \text{ miles} \times 7.77 \frac{\text{applications}}{\text{year}}$$

= 49 treated miles/year

TABLE 4-34. (continued)

Step 7 - Consult the Appropriate Program Implementation Alternatives Table and Select the Desired Program Implementation Plan

From Table 4-37, the following implementation plan and associated costs are anticipated:

	Cost		
	Capital	Unit cost	
Selected Alternative	investment, $	$/Treated mile	$/Actual mile
1. Purchase Coherex® and ship in truck tanker		4,650	
2. Store in newly purchased storage tank	30,000		
3. Prepare road with plant owned grader			630
4. Pump water from river or lake	5,000		
5. Apply chemical with plant owned application truck (includes labor to pump water and Coherex® and apply solution)	70,000	135	
	105,000	4,785	630

Step 8 - Calculate Total Annual Cost by Annualizing Capital Costs and Adding to Annual Operation and Maintenance Costs

Calculate annual capital investment (PI) = capital investment x CRF

$$CRF = [i(1+i)^n]/[(1+i)^n-1]$$

CRF = capital recovery factor
i = 0.15
n = 10 years

CRF = 0.199252

PI = 105,000 x 0.199252 = $20,900/year

Calculate annual operation and maintenance costs (MO)

$$MO = \$4,785/\text{treated mile} \times 49 \text{ treated miles/year} + \$630/\text{actual mile} \times 6.3 \frac{\text{actual miles}}{\text{year}}$$

= $238,000/year

TABLE 4-34. (concluded)

Calculate total cost (D) = PI + MO

D = \$20,900/year + \$238,000/year

= \$258,900/year

Scale total cost by actual road width:

$$\text{Actual total cost for a 30-ft wide road} = \$258{,}900/\text{year} \times \frac{30\ \text{ft}}{40\ \text{ft}}$$

$$= \$194{,}200/\text{year}$$

Step 9 - Calculate Cost Effectiveness by Dividing Total Annual Costs (from Step 8) by the Annual Uncontrolled Emission Rate (from Step 3) and by the Desired Control Efficiency Fraction (from Step 1)

$$\text{Cost effectiveness} = \frac{\$194{,}200/\text{year}}{286\ \text{ST/year} \times 0.9}$$

$$= \$754/\text{short ton of } PM_{10} \text{ reduced}$$

TABLE 4-35. ALTERNATIVE CONTROL PROGRAM DESIGN FOR COHEREX® APPLIED TO TRAVEL SURFACES[a]

Average percent control desired	Particle size[b]	Vehicle passes between applications	Days between applications as a function of ADT[c]		
			100	300	500
50	TP	41,800	418	139	84
	IP	26,200	262	87	52
	PM-10	23,300	233	78	47
75	TP	19,600	196	65	39
	IP	12,900	129	43	26
	PM-10	11,600	116	39	23
90	TP	6,200	62	21	12
	IP	4,900	49	16	10
	PM-10	4,650	47	16	9

[a] Calculated time and vehicle passes between application are based on the following conditions:

Suppressant application:
- 3.7 L of 20% solution/m^2 (0.83 gal. of 20% solution/yd^2); initial application
- 4.5 L of 12% solution/m^2 (1.0 gal. of 12% solution/yd^2); reapplications

Vehicular traffic:
- Average weight--39 Mg (43 tons)
- Average wheels--6
- Average speed--29 km/hr (20 mph)

Road structure: bearing strength--low to moderate

[b] TP = particles of all sizes.
IP = particles < 15 μmA.
PM-10 = particles < 10 μmA.

[c] For reapplications that span time periods greater than 365 days, the effects of the freeze-thaw cycle are not incorporated in the reported values.

TABLE 4-36. ALTERNATIVE CONTROL PROGRAM DESIGN FOR PETRO TAC APPLIED TO UNPAVED TRAVEL SURFACES[a]

Average percent control desired	Particle size[b]	Vehicle passes between applications	Days between applications as a function of ADT[c] 100	300	500
50	TP	107,000	1,070	357	214
	IP	80,600	806	269	161
	PM-10	92,000	920	307	184
75	TP	44,700	447	149	89
	IP	41,900	419	140	84
	PM-10	47,800	478	159	96
90	TP	7,250	72	24	14
	IP	18,600	186	62	37
	PM-10	21,200	212	71	42

[a]Calculated time and vehicle passes between application are based on the following conditions:

Suppressant application: 3.2 L of 20% solution/m^2 (0.7 gal. of 20% solution/yd^2); each application
Vehicular traffic:
- Average weight--27 Mg (30 tons)
- Average wheels--9.2
- Average speed--22 km/h (15 mph)

Road structure: bearing strength--low to moderate

[b] TP = particles of all sizes.
IP = particles < 15 µmA.
PM-10 = particles < 10 µmA.

[c] For reapplications that span time periods greater than 365 days, the effects of the freeze-thaw cycle are not incorporated in the reported values.

One Table?

TABLE 4-37. IDENTIFICATION AND COST ESTIMATION OF COHEREX® CONTROL ALTERNATIVES

Program implementation alternatives	Coherex Cost	Petro Tac
I. Purchase and ship Coherex®		
A. Ship in railcar tanker (11,000-22,000 gal/tanker)	$4,650/treated mile	
B. Ship in truck tanker (4,000-6,000 gal/tanker)	$4,650/treated mile	5400
C. Ship in drums via truck (55 gal/drum)	$7,040/treated mile	11,500
II. Store Coherex®		
A. Store on plant property		
1. In new storage tank	$30,000 capital	
2. In existing storage tank		
a. Needs refurbishing	$5,400 capital	
b. Needs no refurbishing	-0-	
3. In railcar tanker		
a. Own railcar	-0-	
b. Pay demurrage	$20, $30, $60/treated mile	
4. In truck tanker		
a. Own truck	-0-	
b. Pay demurrage	$70/treated mile	
5. In drums	-0-	
B. Store in contractor tanks	$140/treated mile	
III. Prepare road		
A. Use plant-owned grader to minimize ruts and low spots	$630/actual mile	
B. Rent contractor grader	$1,200/actual mile	
C. Perform no road preparation	-0-	
IV. Mix Coherex® and water in application truck		
A. Load Coherex® into spray truck		
1. Pump Coherex® from storage tank or drums into application truck	Tank - 0 (included in price of storage tank) Drums - $1,000 capital	
2. Pour Coherex® from drums into application truck, using forklift	$1,000/treated mile	

TABLE 4-37. (concluded)

Program implementation alternatives	Cost
B. Load water into application truck	
1. Pump from river or lake	$5,000 capital
2. Take from city water line	$40/treated mile
V. Apply Coherex® solution via surface spraying	
A. Use plant owned application truck	$70,000 capital + $135/treated mile for tank or $270/treated mile for drums
B. Rent contractor application truck	Tank - $500/treated mile Drums - $1,000/treated mile

TABLE 4-38. IDENTIFICATION AND COST ESTIMATION OF PETRO TAC CONTROL ALTERNATIVES

Program implementation alternatives	Cost
I. Purchase and ship Petro Tac	
A. Ship in truck tanker (4,000-6,000 gal/tanker)	$5,400/treated mile
B. Ship in drums via truck (55 gal/drum)	$11,500/treated mile
II. Store Petro Tac	
A. Store on plant property	
1. In new storage tank	$30,000 capital
2. In existing storage tank	
a. Needs refurbishing	$5,400 capital
b. Needs no refurbishing	-0-
3. In railcar tanker	
a. Own railcar	-0-
b. Pay demurrage	$20, $30, $60/treated mile
4. In truck tanker	
a. Own truck	-0-
b. Pay demurrage	$70/treated mile
5. In drums	-0-
B. Store in contractor tanks	$140/treated mile
III. Prepare road	
A. Use plant owned grader to minimize ruts and low spots	$630/actual mile
B. Rent contractor grader	$1,200/actual mile
C. Perform no road preparation	-0-
IV. Mix Petro Tac and water in application truck	
A. Load Petro Tac into spray truck	
1. Pump Petro Tac from storage tank or drums into application truck	Tank - 0 (included in price of storage tank) Drums - $1,000 capital
2. Pour Petro Tac from drums into application truck, generally using forklift	$1,000/treated mile
B. Load water into application truck	
1. Pump from river or lake	$5,000 capital
2. Take from city water line	$40/treated mile

TABLE 4-38. (concluded)

Program implementation alternatives	Cost
V. Apply Petro Tac solution via surface spraying	
A. Use plant-owned application truck	$70,000 capital + $135/ treated mile for tank or $270/treated mile for drums
B. Rent contractor application truck	Tank - $500/treated mile Drums - $1,000/treated mile

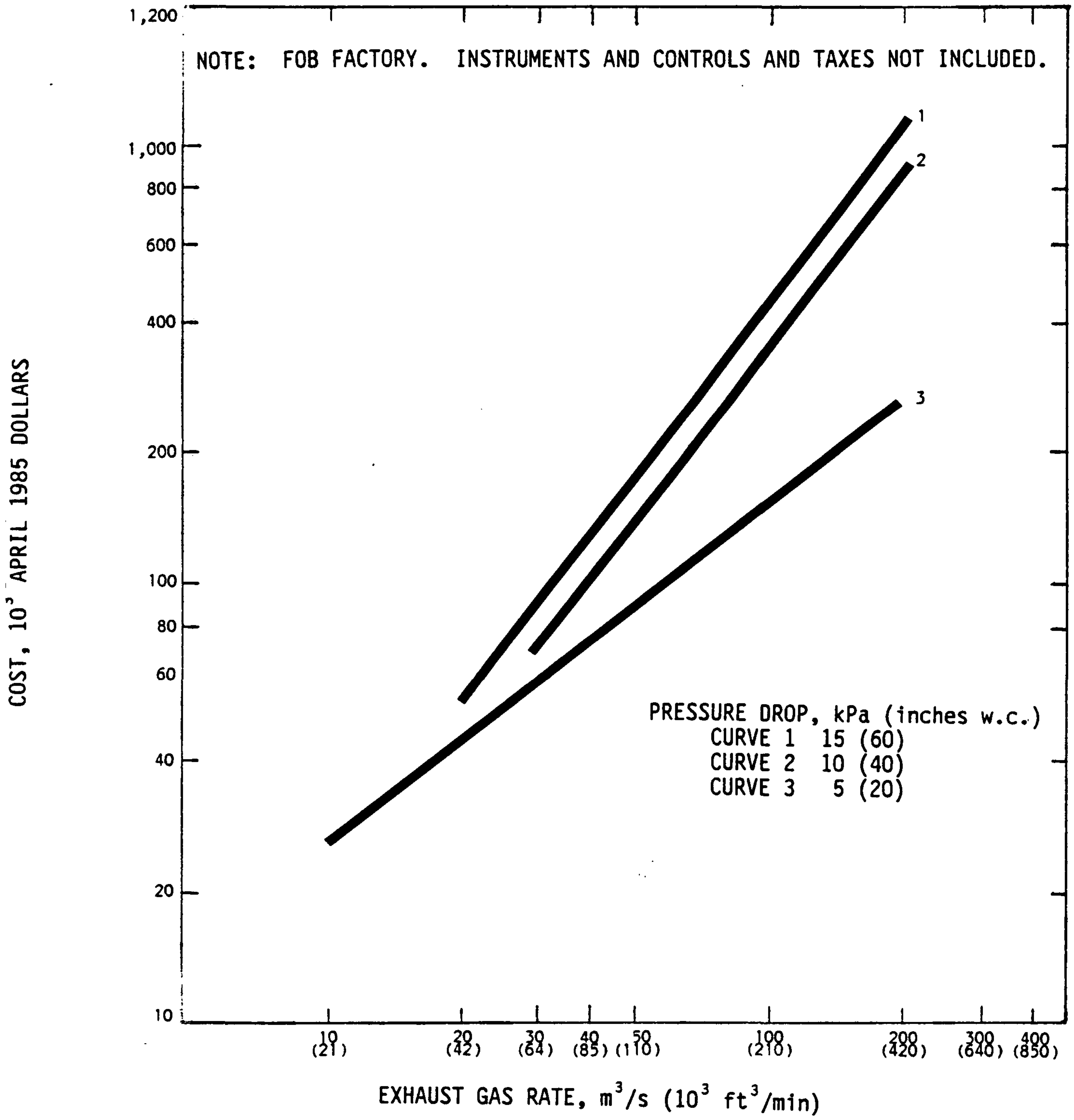


Figure 4-1. Cost of venturi scrubbers, unlined throat with carbon steel construction.

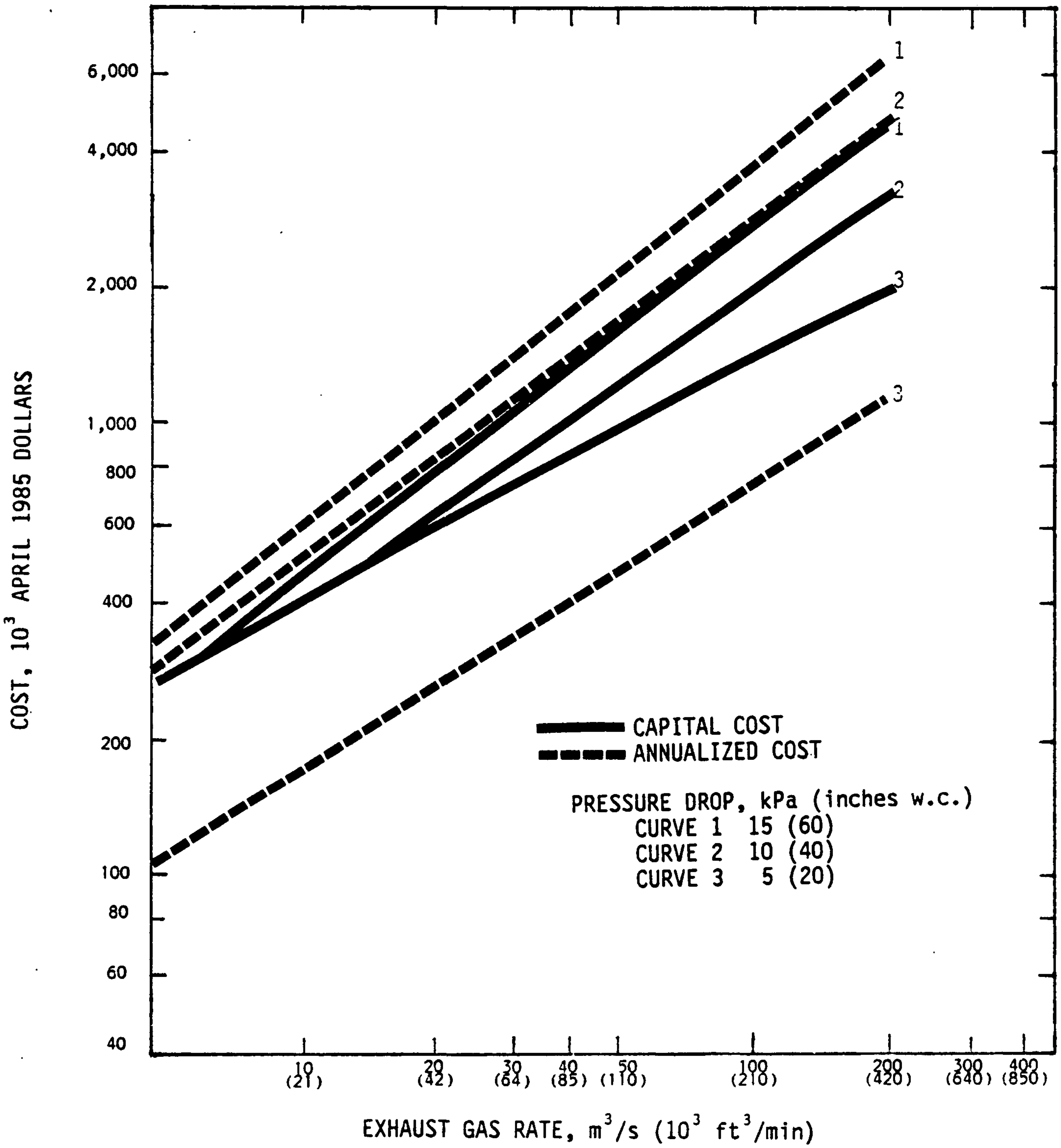


Figure 4-2. Capital and annualized costs of venturi scrubbers with carbon steel construction.

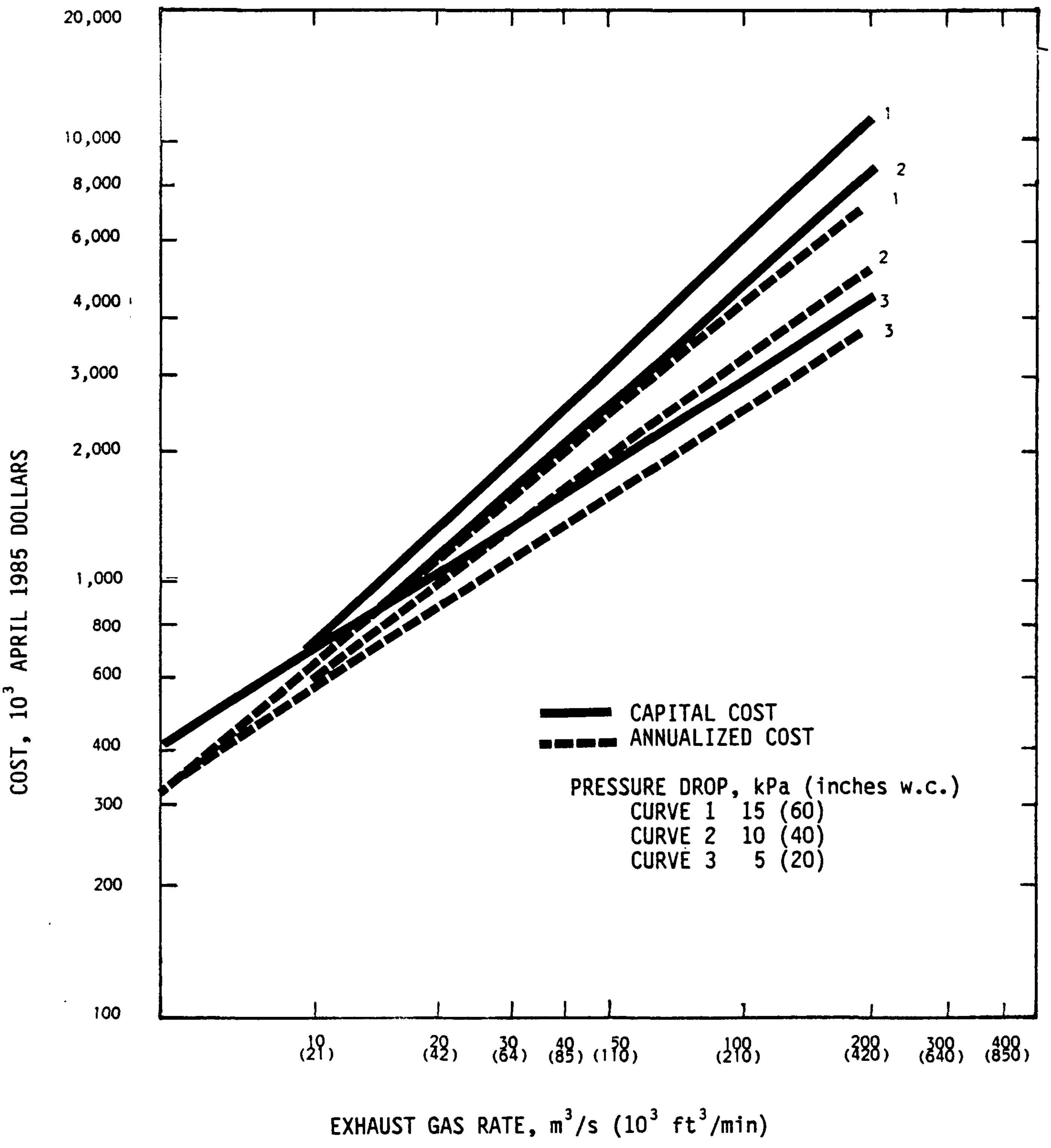
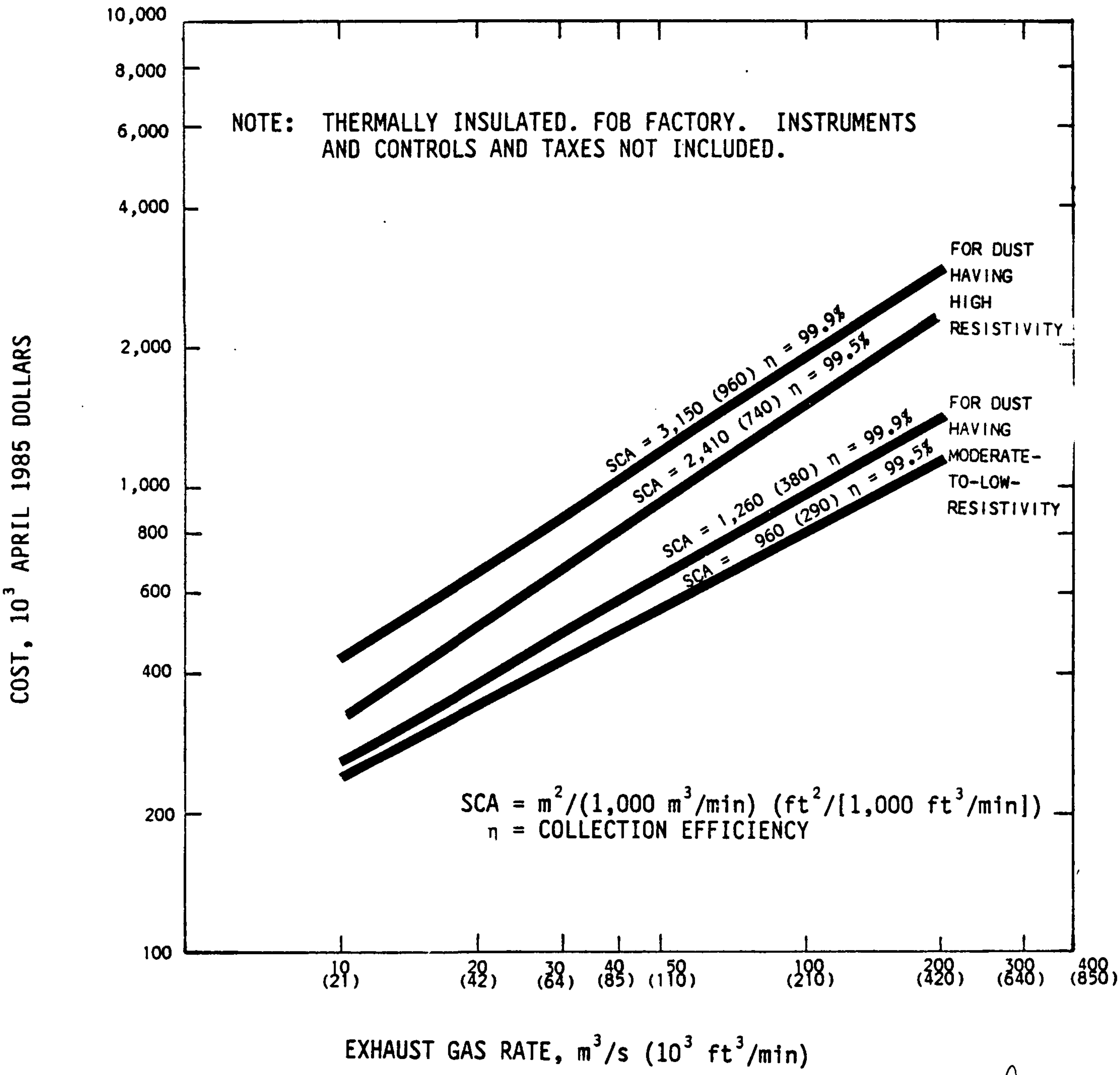


Figure 4-3. Capital and annualized costs of venturi scrubbers with stainless steel construction.



Ref?

Figure 4-4. Cost of electrostatic precipitators with carbon steel construction.

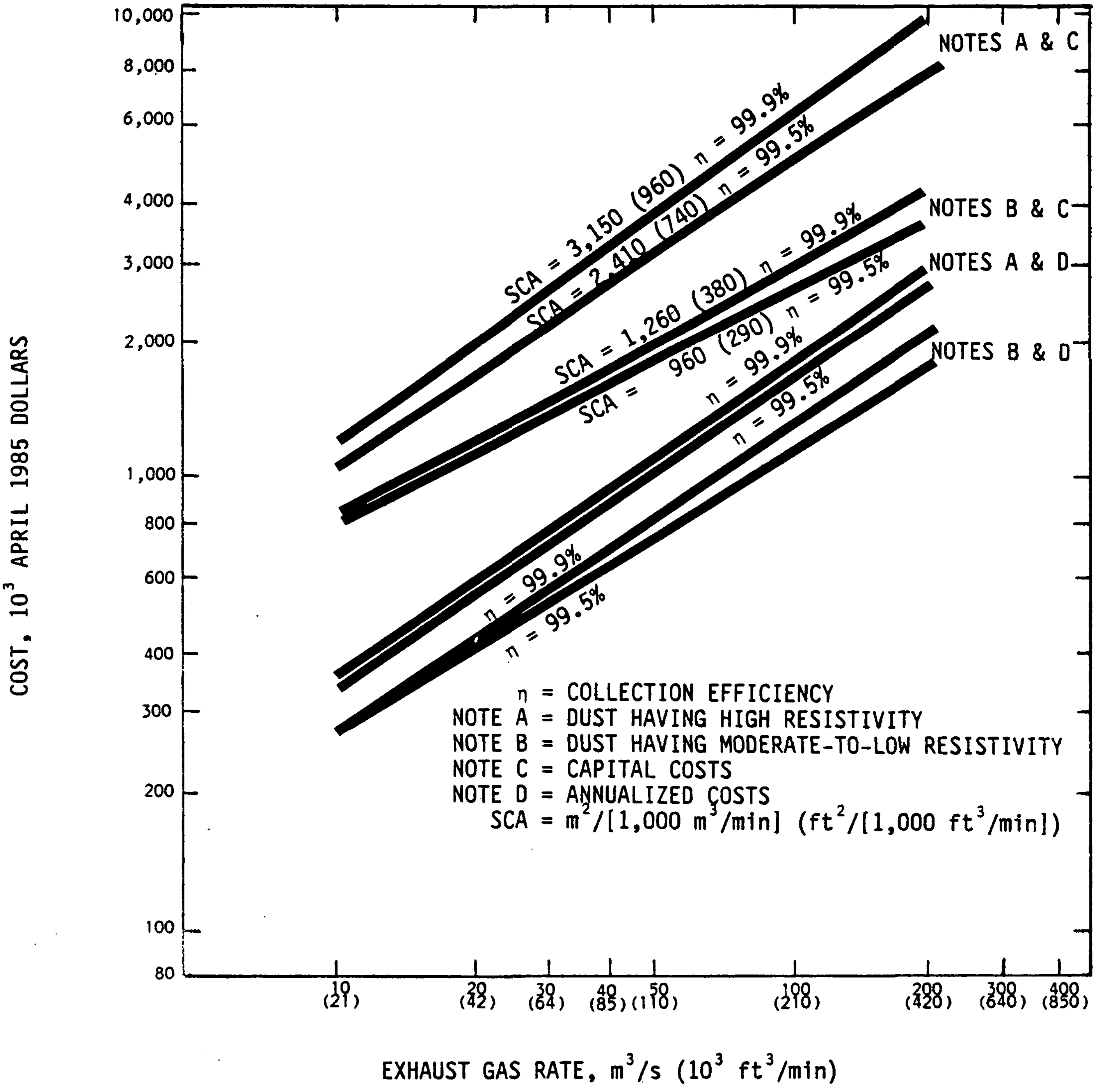


Figure 4-5. Capital and annualized costs of electrostatic with carbon steel construction.

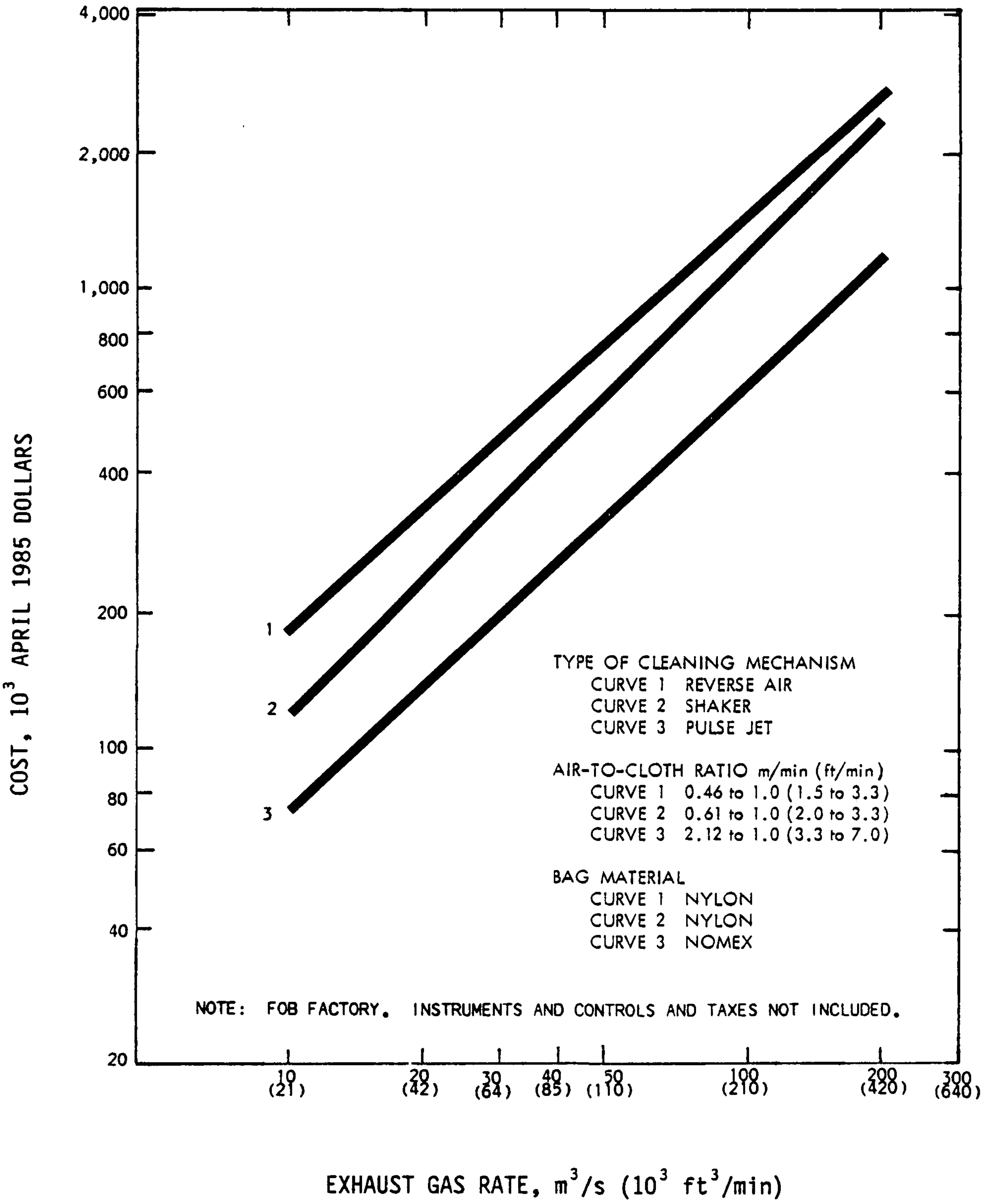


Figure 4-6. Cost of fabric filters with carbon steel construction.

Curves come from

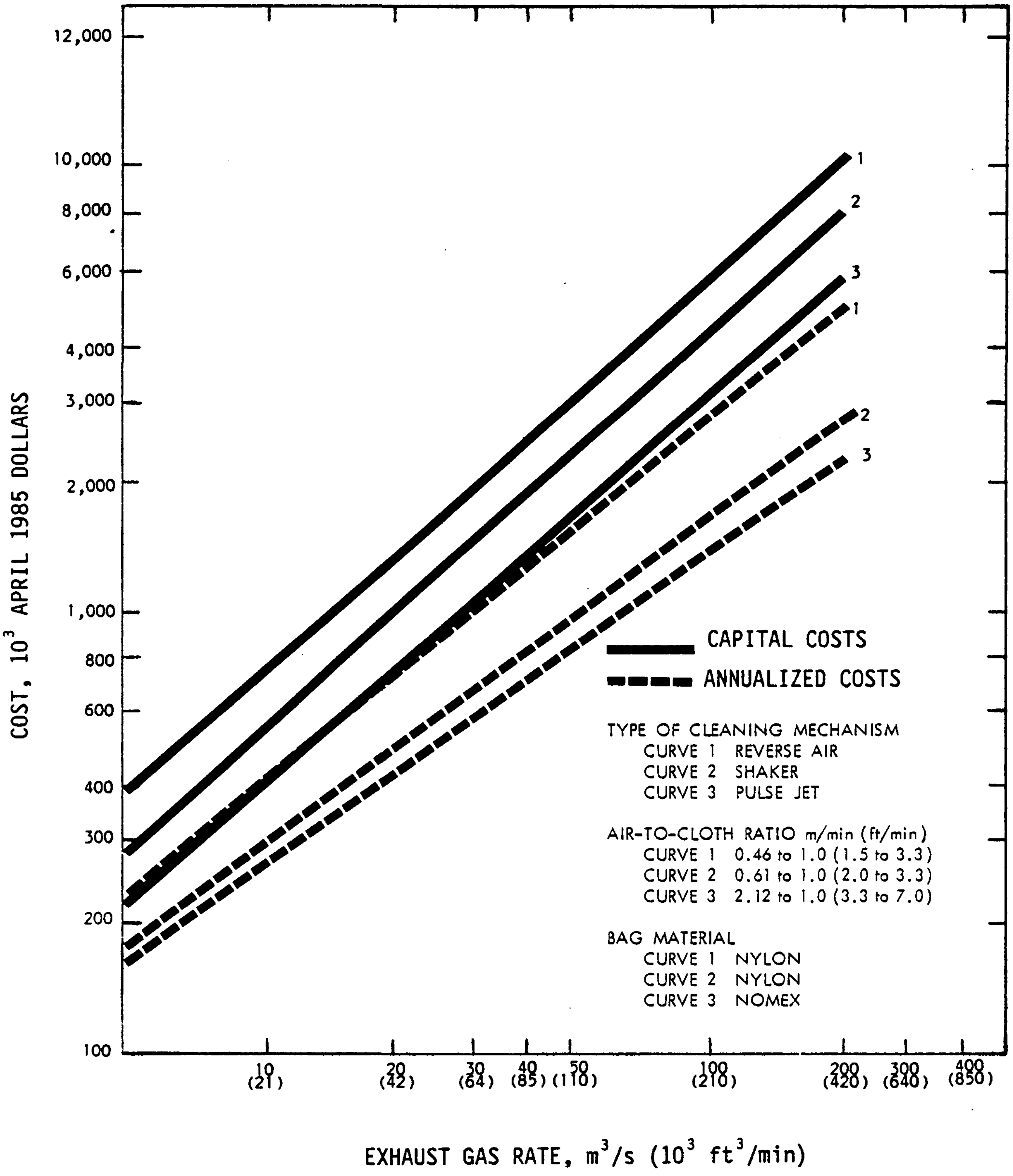


Figure 4-7. Capital and annualized costs of fabric filters with stainless steel construction.

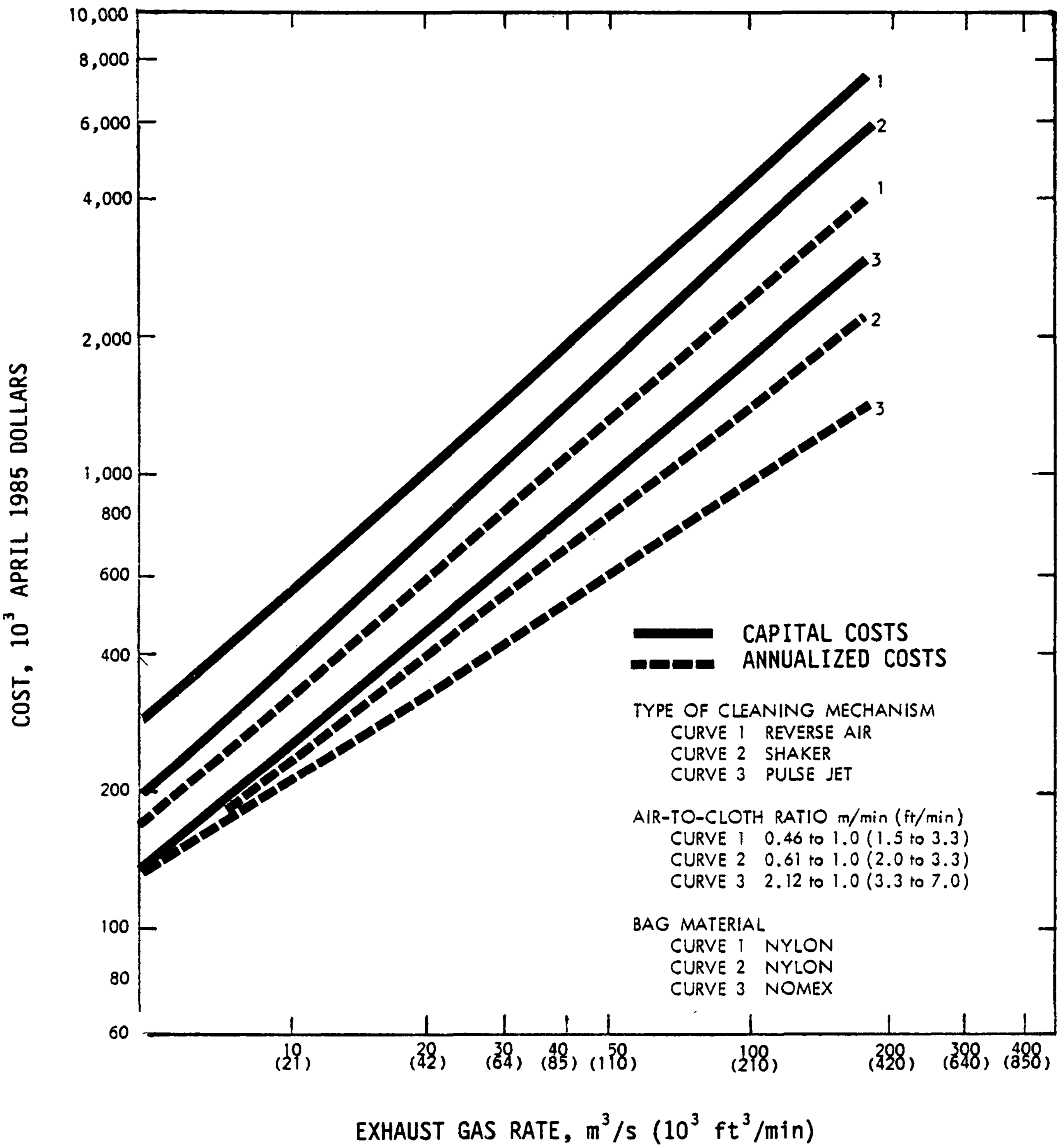


Figure 4-8. Capital and annualized costs of fabric filters with carbon steel construction.

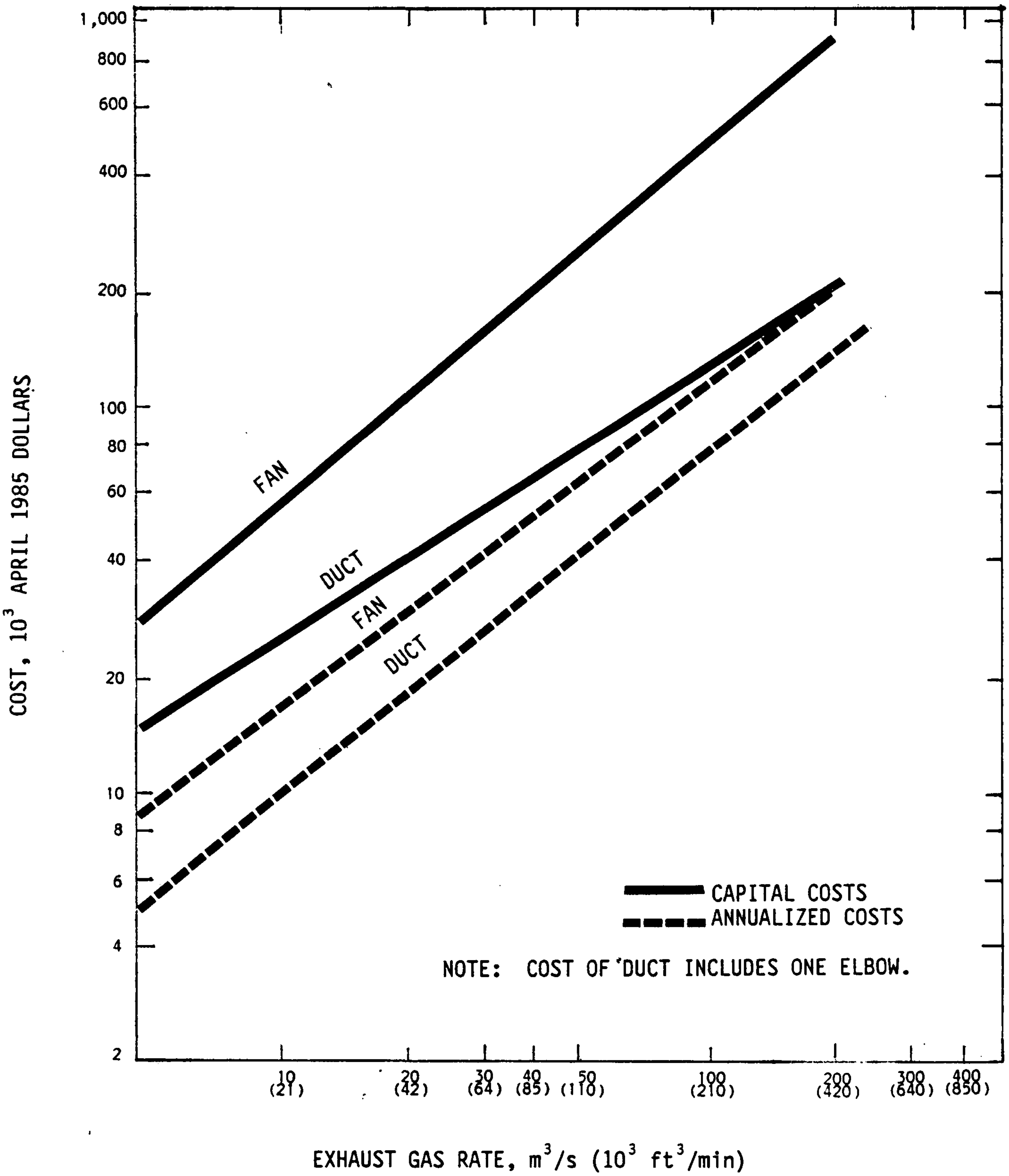


Figure 4-9. Capital and annualized costs of fans and 30.5 m (100 ft) length of duct.

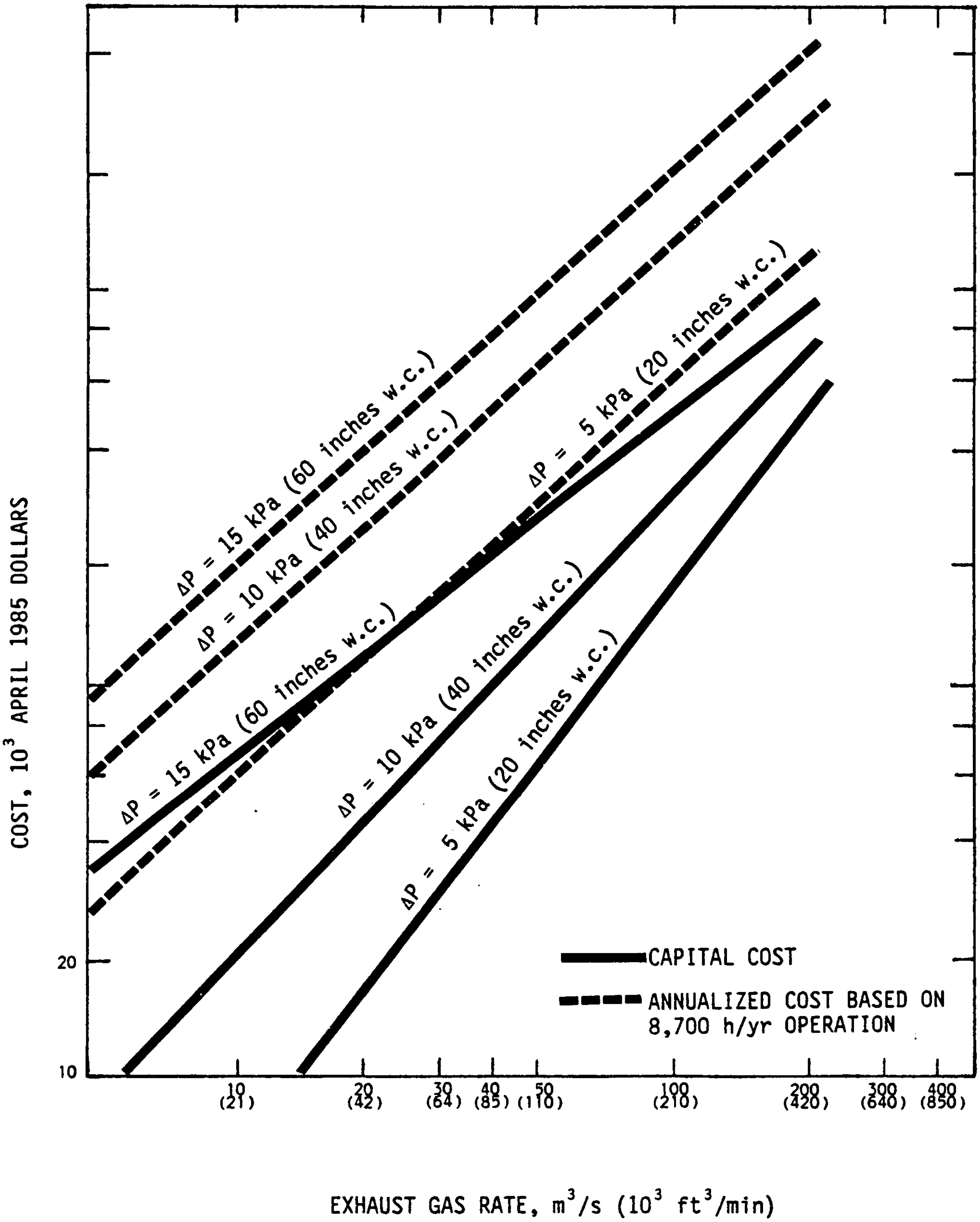


Figure 4-10. Capital and annualized costs of fan driver for various head pressures.

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Needs review! SSCD never submitted comments.

SECTION 5.0

METHODS OF COMPLIANCE DETERMINATION

Once a specific PM_{10} control strategy has been developed and implemented, it becomes necessary for either the control agency or industrial concern to assure that it is achieving the desired level of control. As stated previously, the control efficiency actually attained by a particular technique depends on its proper implementation. This section will discuss methods for determining compliance with various regulatory requirements relating to PM_{10} control strategies. These methods include source testing, visual observations, and other techniques such as recordkeeping of key control parameters.

5.1 SOURCE TESTING METHODS FOR PM_{10}

5.1.1 Ducted Source Testing Methods

As part of the SIP process, the promulgation of a revised NAAQS for PM_{10} will necessitate the development of appropriate size-specific particulate emission standards for ducted sources. In order to determine compliance with these standards (as well as assist in their development), an appropriate methodology must be used to determine the emission rate of PM_{10}.

At present, no standard technique has been developed specifically for the measurement of PM_{10} from ducted sources. However, interim guidelines have been prepared to assist regulatory and industry personnel in conducting this determination until such time that a standard reference test method is published by EPA. These guidelines are presented in Appendix C of Reference 1 which will be described below.[1]

Since PM_{10} is defined as particulate matter equal to or less than 10 μm in aerodynamic diameter, some type of inertial sizing technique is most appropriate for use in source testing. Of the available instruments, either a multistage cascade impactor or a single-stage cyclone collector would be suitable for this purpose. Cyclones offer the advantage of low particle bounce and thus are generally preferred over impactors, with the stipulation that an empirical calibration be conducted prior to use in the field. Sampling trains which incorporate an inertial sizing device are illustrated in Figures 5-1 and 5-2 for noncondensible and condensible particulate emissions, respectively.[1]

The use of an inertial sizing technique does have the inherent problem that isokinetic sampling cannot usually be conducted in the traditional sense (i.e., EPA Method 5). This is due to the fact that inertial devices must be operated at a constant flow rate to maintain their size fractionation characteristics (i.e., cut-points). Thus, adjustment of the flow rate cannot generally be conducted to achieve isokinetic sampling conditions during a multipoint traverse of the duct.

There are a number of approaches which have been proposed to solve the above sampling problem. These approaches include: the Simulated Method 5 (SIM-5) technique; the emission gas recycle (EGR) system; and a method based on the sampling protocol developed for the IP characterization program.[2-4] Each will be discussed below.

In the SIM-5 technique, a standard fixed-flow sampler is used with anisokinetic sampling errors kept within reasonable limits by setting velocity criteria on a point-by-point basis.[2] Sampling nozzles are changed, as necessary, during testing to match the sampling velocity to the duct velocity within ±20% of isokinetic conditions. Since the flow rate cannot be changed, the duration of sampling is varied from point to point to be proportional to the local velocity. The sample volume obtained is proportional to the total volumetric flow through the area represented by each sampling point.[2] The SIM-5 method involves a rather complex calculation procedure and thus would be fairly difficult to implement routinely.

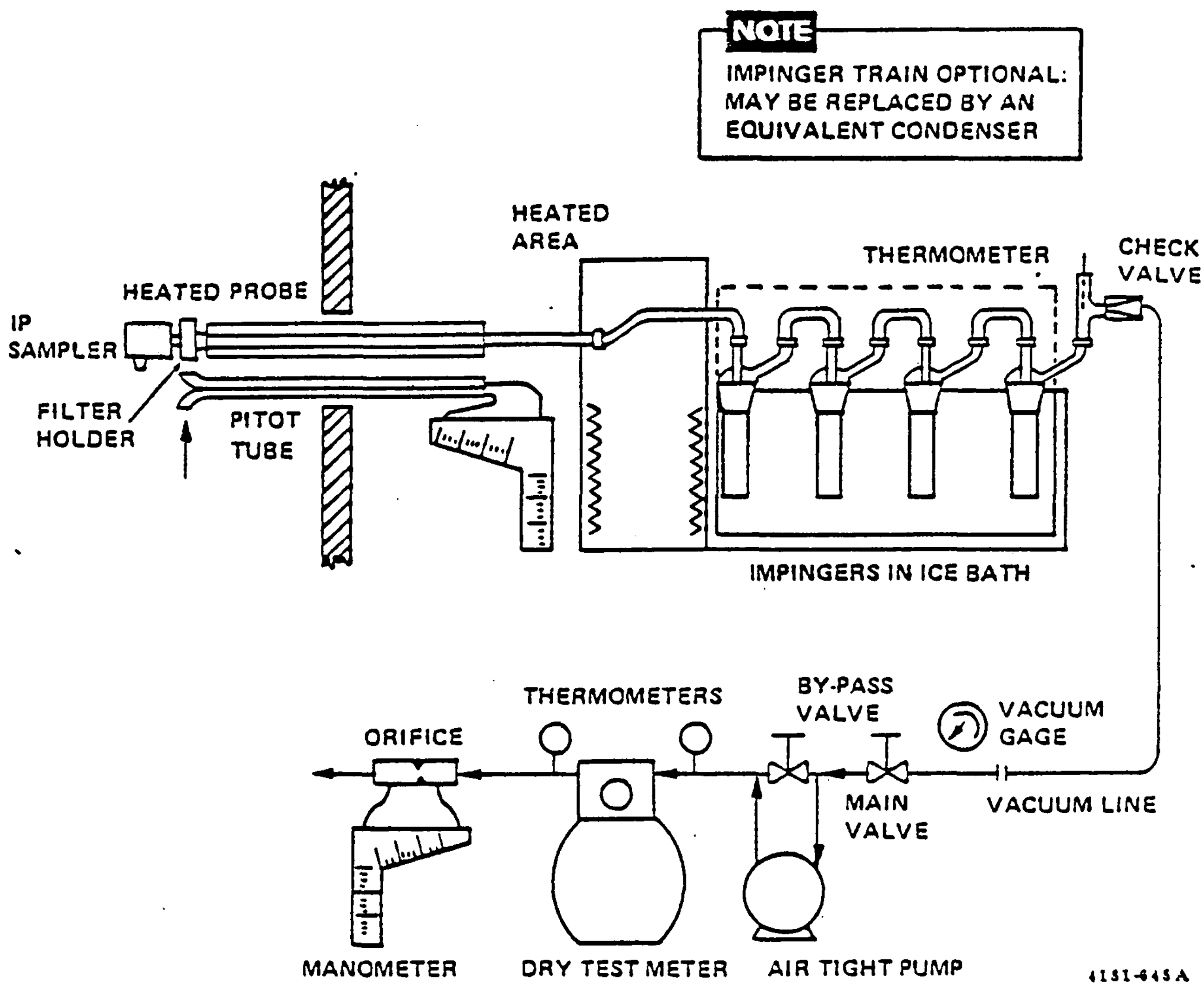

Figure 5-1. PM_{10} particulate sampling train for noncondensible particulate (Modified EPA Method 5 train).[1]

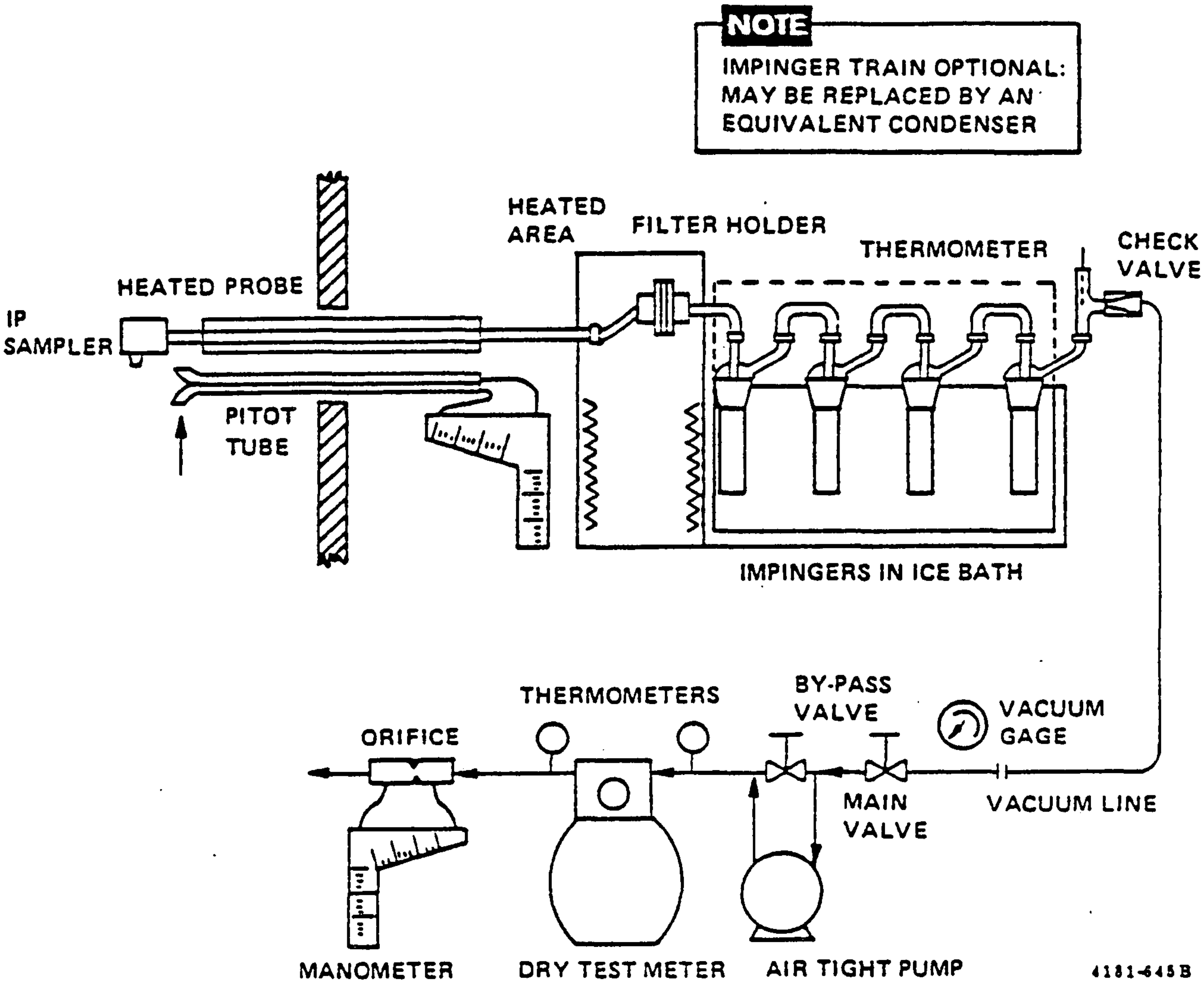

Figure 5-2. PM_{10} particulate sampling train for condensible and noncondensible particulate (Modified EPA Method 5 train).[1]

The EGR system, currently under evaluation by EPA, involves the incorporation of a recirculation loop in the sampling train to augment the sample flow through an inertial sizing device.[3] A fixed flow is thus maintained through the inertial classifier while allowing the sampling rate to be varied from point-to-point in the traditional (i.e., Method 5) manner. This system is by far the easiest of the three methods to implement. A diagram of the current EGR system is shown in Figure 5-3.[3]

Lastly, a method based on the protocol originally developed for the EPA's inhalable particulate (IP) research program could also be used for conducting PM_{10} compliance tests.[4,5] In this method, a series of single-point samples are collected using a standard inertial classifier and appropriately sized nozzles which are subsequently combined to synthesize a complete traverse. It is currently recommended that a four-point grid be used with a sample collected from each grid location to make up a single test run (Figure 5-4).[1] Triplicate runs are to be conducted for each duct tested to obtain a total of 12 individual samples. This technique has been found to be extremely laborous, time-consuming, and difficult to perform on a routine basis.

Finally, additional guidelines on the selection and operation of PM_{10} samplers and sampling trains can be found in Reference 1. The reader is directed to these guidelines for supplementary details on this subject.

5.1.2 Fugitive Source Testing Methods

Although a number of different techniques have been developed over the years to determine mass emissions from fugitive sources, the only reference method which has been published by EPA is Method 14 for Primary Aluminum Potroom Roof Monitors.[6] This method involves the installation of a sampling manifold containing large-diameter nozzles. A large volume of effluent is collected by the system from the roof monitor(s) and subsequently transported to ground-level through a duct. A blower connected to the duct is used to extract and exhaust the sample flow. Standard source sampling techniques (i.e., Method 13A or 13B) are then used to determine appropriate mass emission rates from the potroom.

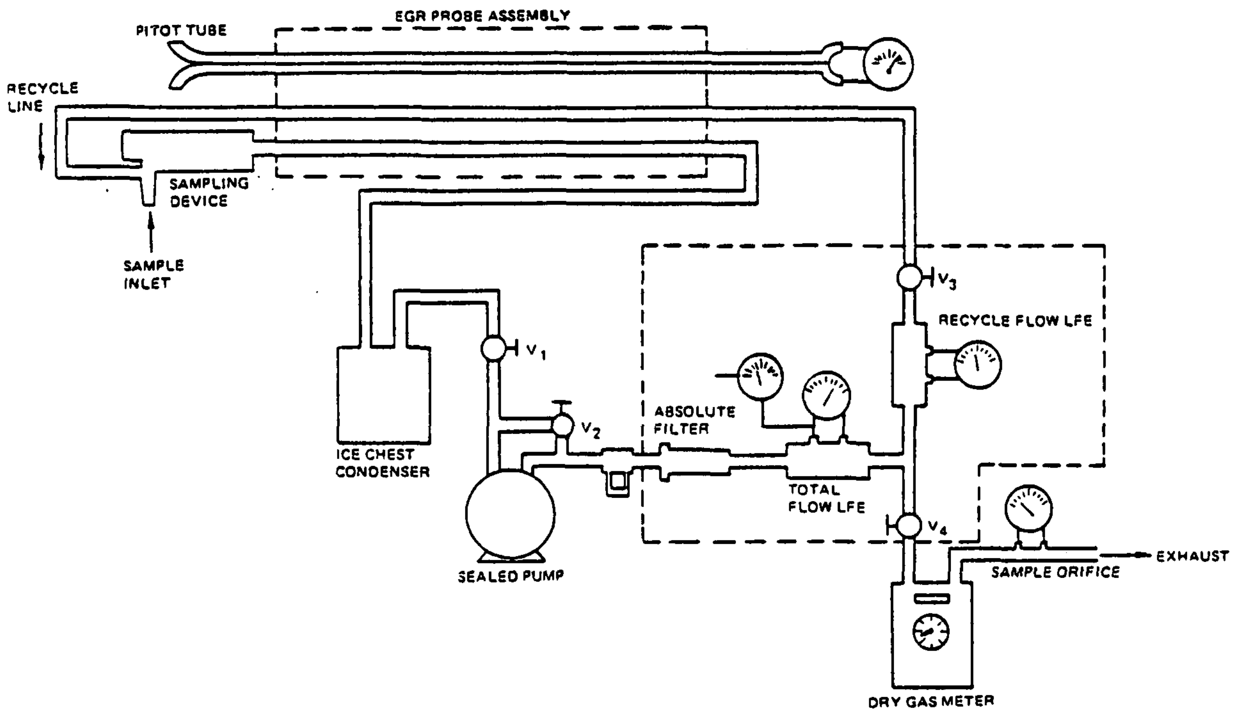

Figure 5-3. Schematic of the Emission Gas Recycle (EGR) sampling train.[3]

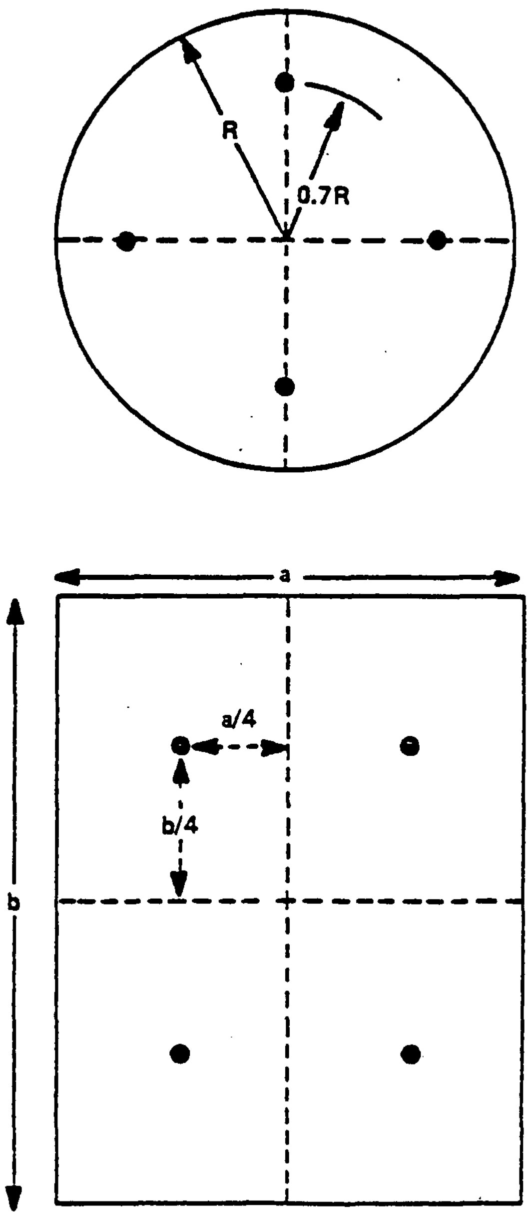

Figure 5-4. Recommended sampling points for circular and square or rectangular ducts.[1]

Since traditional source testing methods are used to determine mass emissions from potroom roof monitors, there is no reason why one of the methods discussed in Section 5.1.1 above could not also be used to determine the emissions of PM_{10} from this source as well. However, as would be the case for any ducted source, similar limitations to those discussed previously regarding the methodology to be used would also apply to this particular application.

5.2 METHODS FOR DETERMINING VISIBLE EMISSIONS

5.2.1 Federal Reading Methods

As a compliance tool, the determination of visible emissions (VE) has a long history of application to stationary sources. At the federal level, use of VE as a compliance tool is reflected in the specification of three methods:

- Method 9 - Visual determination of the opacity of emissions from stationary sources.
- (Modified) Method 9 - For basic oxygen furnace processes.
- Method 22 - Visual determination of fugitive emissions from material processing sources.

For compliance purposes, Tables 5-1 to 5-3 summarize the major features of each visual observation method.

Method 9 (M9) is the most familiar of the observation methods. It is widely used in the evaluation of stack emissions. Important advantages of M9 include:[7]

TABLE 5-1. SUMMARY OF EPA METHOD 9 REQUIREMENTS (M9)

Reader Position/Techniques

- Sun must be in 140° sector behind the reader.
- Plume direction should be as near perpendicular to reader line of sight as possible.
- Plume should be read at point of greatest opacity, excluding condensed water vapor.
- Only one plume thickness should be read.
- Individual opacity observations taken each 15 sec, recorded to the nearest 5% opacity.

Data Reduction

- 6-min time-average consisting of 24 consecutive 15-sec readings.

Certification

- Based on results of 25 white and 25 black plumes read consecutively with the following error margins:
  - No individual reading with error > 15% opacity.
  - Average error over set of 25 readings < 7.5% opacity (black or white plumes)
  - Certification is valid for period of 6 months.
  - Smoke generator must meet given specifications.

TABLE 5-2. SUMMARY OF MODIFIED EPA METHOD 9 FOR BASIC OXYGEN PROCESS FURNACES (MM9)

Reader Position/Techniques (Differences from Method 9)

- Plume considered to consist of aggregate of emissions from given building opening.
- Observations taken from minimum of three steel production cycles.

Data Reduction

- 3-min time-average consisting of 12 consecutive 15-sec readings.

Certification (Same as Method 9)

TABLE 5-3. SUMMARY OF EPA METHOD 22 REQUIREMENTS (M22)

Reader Position/Techniques

- For outdoor locations sun must not be directly in observers eyes.
- For indoor location proper application requires illumination > 100 lux (10-ft candles). Determination requires light meter (50-200 lux range).
- Observer position > 15 ft, < 0.25 mi.
- Continuous observation for visible emissions regardless of level. Period of observation > 6 min, not to exceed 15-20 min without rest break. Break > 5 min ≦ 10 min.
- Method requires two stop watches (unit division at least 0.5 sec).
- Stopwatch 1 - used to record duration of observation period.
- Stopwatch 2 - used to record duration of visible emissions.

Data Reduction

- Comparison of duration of visible emissions (stopwatch 2) to total observation period (stopwatch 1) according to applicable regulations.

Certification

- No specific requirements.

- M9 is detailed and formally promulgated.

- M9 includes opacity observation procedures, data reduction methods, and certification requirements.

- M9 is consistent with New Source Performance Standards (NSPS) that limit opacity based on a 6-min average.

- M9 has supporting data on the accuracy of the method which should be considered in determining possible violations.

Disadvantages of M9 are:

- M9 is not compatible with time exemption regulations.

- M9 is not suitable for evaluation of some intermittent emissions.

To determine compliance with Basic Oxygen Process Furnaces (BOPF) shop roof monitor standards, certain modifications have been made to M9.[8] Table 5-2 summarizes the primary method changes. It is important to note that for this determination VE observers should position themselves to read across the shortest dimension of the roof monitor rather than through the long dimension from the end of the monitor. The latter position would result in a high bias in opacity determinations.[8]

The third EPA reading method, Method 22 (M22), is specified as appropriate for determining fugitive emissions from materials processing sources.[9] In this method, sources of concern include emissions that:

1. Escape capture by process equipment exhaust hoods;

2. Are emitted during materials transfer;

3. Are emitted from buildings housing material; and

4. Are emitted directly from process equipment.

M22 is one example of time-aggregating opacity observations. This method uses continuous observation based on the comparison of emission time (i.e., accumulated time with observed opacity ≧ 5%) to total observation time.

5.2.2 Other Reading Methods

None of the previously discussed federal methods are directed specifically at the evaluation of VE from open sources. However, based in part on federal procedures, the State of Tennessee has developed a method (TVEE Method 1) for evaluating VE from roads and parking lots.[10] The following discussion focuses on TVEE Method 1 (M1) comparing it to the federal methods in the technical areas: (1) reader position/techniques; and (2) data reduction/evaluation procedures. Table 5-4 summarizes the relevant features of TVEE M1.

5.2.1.1 Reader Position/Techniques--

As indicated in Table 5-4, TVEE Method 1 adopts the EPA Method 9 (M9) criterion for observer position relative to the sun (140-degree sector behind the reader). M1 specifies an observer location of 15 ft from the source; that is the minimum distance called for in EPA Method 22 (M22).[11] In most cases, this distance should allow an unobstructed view, and at the same time meet observer safety requirements.

M1 also specifies that the plume be read at ~ 4 ft directly above the emitting surface. This specification presumably results from field experiments conducted to support the method. It is probably intended to represent the point (i.e., location) of maximum opacity as read in M9. While there is no quantitative supporting evidence, it seems likely that the height and location of maximum opacity relative to a passing vehicle will vary depending upon ambient factors (wind speed and direction) as well as vehicle type and speed.

TABLE 5-4. SUMMARY OF TVEE METHOD 1 REQUIREMENTS (M1)

Reader Position/Techniques
• Sun in 140° sector behind the reader.
• Observer position ~ 15 ft from source.
• Observer line of sight should be as perpendicular as possible to both plume and wind direction.
• Only one plume thickness read.
• Plume read at ~ 4 ft directly above emitting surface.
• Individual opacity readings taken each 15 sec, recorded to nearest 5% opacity.
• Readings terminated if vehicle obstructs line of sight.
• Readings terminated if vehicles passing in opposite direction creates intermixed plume.
Data Reduction
• Two-min time-averages consisting of eight consecutive 15-sec readings.
Certification
• Per Tennessee requirements

Implied in the M1 specification that the plume be read ~ 4 ft above the emitting surface, is the fact that observations will be made against a terrestrial (vegetation) background. The results of one study using a conventional smoke generator modified to emit horizontal plumes, indicated that under these conditions observers are likely to underestimate opacity levels by even greater margins than those typically associated with M9.[12] More specifically, the study found that as opacity levels increased, opacity readings showed an increasing negative bias. For example, at 15% opacity, the observers underestimated opacity by about 5%, and at 40% opacity, observations averaged about 11% low.[12] Black plumes were underestimated at all opacity levels.

M1 specifies that only one plume thickness be read which is consistent with all the federal methods. It includes qualifying provisions that: (1) readings terminate if vehicles passing in opposite directions create an intermixed plume; but (2) readings continue if intermixing occurs as a result of vehicles moving in the same direction. Unlike (1), the latter condition is considered representative of the surface. The first specification is comparable to the specification found in M9 for multiple stacks (e.g., stub stacks on baghouses). The intent here is probably to minimize the influence of increasing plume density which results from "overlaying" multiple plumes.

Finally, M1 specifies nominal 15-sec observations comparable to those for M9. This is in contrast to M22 which uses the stopwatch method to record the duration of visible emissions.

5.2.2.2 Data Reduction/Evaluation Procedures--

There are two basic approaches that can be used to reduce opacity readings for comparison with VE regulations. One approach involves the time-averaging of consecutive 15-sec observations over a specified time period to produce an average opacity value. M9 uses this approach by calculating a 6-min value (the average based on 24 consecutive observations). As noted earlier, the 6-min averaging period is inappropriate for open dust sources as these typically produce brief, intermittent opacity peaks rather than a sustained opacity level. As a result, a continuous 6-min period of observation could include a substantial fraction of time with no activity and thus no source of VE. In the development of M1, the State of Tennessee concluded that a shorter averaging period--2 min (i.e., eight consecutive 15-sec readings) was appropriate for roads and parking lots.

Although not specified in M1, VE from open sources could be evaluated using time-aggregating techniques. For example, the discrete 15-sec readings could be employed in the time-aggregating framework. In this case, the individual observations are compiled into a histogram from which the number of observations (or equivalent percent of observation time) in excess of the desired opacity may then be ascertained. The principal advantage of using the time-aggregate technique as a method to reduce VE readings is that the resultant indicator of opacity conditions is then compatible with regulations that include a time exemption clause. Under time exemption standards, a source is permitted opacity in excess of the standard for a specified fraction of the time (e.g., 3 min/hr). The concept of time exemption was originally developed to accommodate stationary source combustion processes.

Without more detailed supporting information, it is difficult to determine which of the two approaches is most appropriate for evaluating VE from open sources. With respect to time-averaging, statistics of observer bias in reading plumes from a smoke generator do indicate at least a slight decrease in the "accuracy" of the mean observed opacity value as averaging time decreases. In M1 (2-min average), this is reflected in the inclusion of an 8.8% buffer for observational error. This buffer is taken into account before issuing a Notice of Violation.[10] For M9, the 6-min average opacity value is typically associated with a maximum observer bias of +7.5%.

One potential problem with applying time-averaging to opacity from roads and parking lots, is that the resulting average will be sensitive to variations in source activity. For example, interpreting one conclusion offered in support of Method 1, it is likely that under moderate wind conditions a single vehicle pass will produce only two opacity readings ≧ 5%.[10] Averaging these with six zero (Ø) readings yields a 2-min value below any reasonable opacity standard. Yet, under the same conditions with two or more vehicle passes, the average value will suggest elevated opacity levels. While there is no information available on the use of time aggregation for open source opacity, it appears that this approach would more easily accommodate variations in level of source activity. For this reason alone, it may be the evaluation approach better suited to roads and parking lots.

5.3 OTHER METHODS FOR DETERMINING COMPLIANCE

5.3.1 Parameter Monitoring for Ducted Source Controls

Federal, State, and local air regulatory agencies are concerned that the methods currently available are not always adequate to determine that sources operate and maintain their control equipment in a compliance mode. Because stack testing provides only a relatively short-term measure of compliance, it is difficult to determine if a source remains in compliance after initial compliance is achieved. The only method currently accepted for measuring continuous compliance is the use of a continuous emission monitor (CEM), although many constraints limit the use of CEM's including the high cost and reliability.

Compliance also may be determined by parameter monitoring. Standard industrial practice includes parameter monitoring to improve quality control, safety in the workplace, and product yield and to provide a means of accounting for raw materials and product use. In the field of environmental control, certain control device parameters have traditionally been measured, and these parameters have been used with varying levels of sophistication to provide an indication of how well the device is performing.

Parameter monitoring provides a useful tool to operators and control agency personnel for the following purposes:

1. To determine a maintenance schedule;

2. To check on operation and maintenance practices;

3. To prevent, detect, and diagnose malfunctions;

4. To assure that appropriate corrective action has been taken in the case of malfunctions;

5. To assure that the control device is operating properly during performance testing; and

6. To assess control equipment performance and compliance on a continuing basis.

Parameter monitoring procedures for ESPs, fabric filters, and wet scrubbers are discussed below.

5.3.1.1. Electrostatic Precipitators--

ESP performance is a function of the electrical power required to charge and attract the particles toward the collection plates. ESP performance parameters are the primary and secondary voltage and current levels for each of the fields or transformer-rectifier (T-R) sets. The voltage and current going to the T-R set is known as the primary voltage and current, respectively. The secondary voltage and current is the electricity going from the T-R set to the high voltage electrodes (wires) inside the ESP. The secondary voltage and current levels are more useful and specific for indicating performance and diagnosing typical malfunctions than are the primary voltage and current levels. If both secondary meters are not available, secondary power levels can be estimated by the following equation:

$$SP = PV \times PC \times EFF \tag{5-1}$$

where: SP = secondary power (watts)

PV = primary voltage (volts)

PC = primary current (amperes)

EFF = T-R set efficiency (percent) = typically 60 to 70%

Secondary power can be more accurately and directly calculated if both secondary meters are available and calibrated by the following equation:

$$SP = SV \times SC \tag{5-2}$$

where: SV = secondary voltage (kV)

SC = secondary current (mA)

After the power level is calculated for each ESP field, one can graph or tabulate the field power levels to determine their interrelationship. The lowest power level is experienced by the inlet field, and the power level steadily increases for the subsequent fields in the direction of gas flow. A malfunction is indicated if the field power levels do not show a steady increase from the inlet field to the outlet field.

Table 5-5 presents recommended parameters for monitoring ESP performance. Secondary ESP performance parameters are gas temperature, moisture content, spark rate, and ash hopper operation. Comparison of the inlet and outlet gas temperature is useful to indicate potential problems with gas in-leakage. ESP performance is sensitive to resistivity, and recordkeeping of inlet gas temperature and moisture content can be used to indicate problems with high resistivity along with spark rate records. Proper operation of the ash hopper and ash handling system is important for short-term and long-term ESP performance, since severe problems in ash removal can cause permanent damage to the high voltage wires and collection plates. Ash hopper heaters and hopper level indicators should be monitored to alert operators of any problems experieced.

TABLE 5-5. RECOMMENDED OPERATING PARAMETERS FOR MONITORING OF ESP PERFORMANCE

- Secondary voltage for each T-R set (kilovolts)
- Secondary current for each T-R set (milliampereres)
- Primary voltage for each T-R set (volts)
- Primary current for each T-R set (amperes)
- Inlet gas temperature (°F)
- Outlet gas temperature (°F)
- Gas moisture content (% H_2O)
- Hopper level indicator
- Hopper heater indicator

5.3.1.2 Fabric Filters--

~~Parameter monitoring is not as significant for fabric filters as for wet scrubbers or ESP's.~~ Opacity monitoring and internal inspection of the tube sheet are the most critical indicators of fabric filter performance.

what looking for?

Inlet gas temperature, bag pressure drop, gas flow rate, bag cleaning parameters, and ash removal indicators are recordable parameters that can indicate performance levels or malfunctions. Inlet gas temperature monitoring will indicate that the appropriate temperature range is maintained above the gas dew point and below the maximum temperature suitable for the bag material. Bag pressure drop monitoring for each compartment can indicate sudden or severe problems with bag blinding, bag cleaning, or bag mounting. Bag cleaning parameter monitoring can indicate malfunctions with the bag cleaning hardware or timers. Ash removal monitoring can indicate malfunctions with the components of the ash handling system. Table 5-6 presents recommended parameters for monitoring of fabric filter performance.

TABLE 5-6. RECOMMENDED OPERATING PARAMETERS FOR MONITORING OF FABRIC FILTER PERFORMANCE

- Inlet gas temperatue (°F)
- Bag pressure drop for each compartment (inches water column)
- Bag cleaning conditions:

  Pulse: Air pressure (pounds per square inch gauge)
  Shake: Shaker motor current (amperes)
  Reverse: Reverse-air fan current (amperes)

- Bag cleaning cycle:

  Pulse: Duration and frequency
  Shake: Duration, frequency and delay periods
  Reverse: Duration, frequency and delay periods

- Fabric filter fan current (amperes)
- Fabric filter fan gas temperature (°F)

Since bag pressure drop is also a function of gas flow rate, monitoring gas flow rate can help diagnose performance problems. Gas flow rate can be indicated by measuring fan current and gas temperature.

Recordkeeping of bag replacement information in conjunction with parameter and opacity monitoring is recommended to assess the adequacy of baghouse operation and maintenance. Bag replacement information includes date and specific location(s) of the bag(s) replaced and a description of bag failure (e.g., bleeding, cuff-seal tear, pinholes, or large holes). Repetition of the same bag failures in the same locations warrant further investigation and inspection.

5.3.1.3 Wet Scrubbers--

Parameter monitoring for wet scrubbers is particularly important because conventional opacity observations of steam plumes are complicated by exhaust gas moisture content, weather conditions, and the variable distances for steam detachment. To monitor the potential degradation in control device performance, parameter monitoring is being recommended to or required of wet scrubber owner/operators in lieu of opacity. The operating parameters selected for monitoring are gas pressure drop across each scrubber and the liquid flow rate to each scrubber. Pressure drop and liquid flow are performance parameters because they indicate the extent of: (1) atomization of water droplets; and (2) the acceleration of particles through the venturi section to become collected by the slower moving droplets. Monitoring of these parameters can indicate malfunctions in the scrubber pumping system (i.e., pumps and piping) and the need to adjust the variable throat opening (if applicable). The example calculation in subsection 4.4.1 includes cost information for this monitoring capability.

Other significant parameters worthy of consideration for monitoring are included in Table 5-7. Total solids concentration monitoring can indicate when spray nozzles become plugged and ineffective. Scrubber water pH monitoring will indicate when the acidity or alkalinity levels need to be adjusted to prevent corrosion damage. When applicable, monitoring the pressure drop across the separator (or mist eliminator) can indicate pluggage or other problems resulting in reentrainment of particle-bearing droplets. Since scrubber and separator pressure drop levels are also dependent upon gas flow rate, monitoring gas flow rate can also help diagnose performance problems. Gas flow rate can be indicated by measuring fan current (amperes) and gas temperature.

TABLE 5-7. RECOMMENDED OPERATING PARAMETERS FOR MONITORING OF WET SCRUBBER PERFORMANCE

- Pressure drop across venturi (inches water column)
- Pressure drop across separator (if separate), inches water column
- Scrubber water feed rate (gallons per minute)
- Scrubber water solids concentration (percent)
- Scrubber water pH level (pH)
- Scrubber fan current (amperes)
- Scrubber fan gas temperature(°F)

5.3.2 Recordkeeping for Open Source Controls

As discussed above, parameter monitoring and associated recordkeeping are important components in ensuring that a control program meets the specified permit objectives. Detailed recordkeeping is particularly important for open source controls as it provides a basis for determining when reapplication of a periodically applied control measure is again needed in order to maintain acceptable levels of control. The following discussion focuses on the types of information that should be recorded for open source, periodically applied control measures.

In many industrial settings, chemical dust suppressants are used to control emissions from unpaved surfaces. Control efficiency data for PM_{10} derived from actual source testing have been discussed previously in Section 3.0. For chemical dust suppressants applied to unpaved surfaces, the key control parameters that should be recorded include:

1. Application procedure.
2. Date of application (and subsequent reapplications).
3. Dilution ratio (parts of chemical/parts of water).
4. Application intensity (L/m^2 or $gal/yard^2$).
5. Quantity of chemicals purchased and used.

Application procedure includes method (i.e., spray truck of known capacity or fixed sprinkler system), number of nozzles in operation, nozzle capacity, and method for storage of chemical (i.e., storage tank or 55-gal. drums). In situations where a storage tank is used for the chemical, a flowmeter should be installed so that the dilution ratio can be verified.

Table 5-8 presents a typical form that can be used to record key parameters for a control program using chemical dust suppressants. This form assumes that facility information concerning number of roadway segments, storage piles, etc., is already compiled in an emissions inventory format, and that control parameters can be recorded with reference to this format.

It should be noted that application intensity is the most difficult of the various parameters to determine directly. However, given appropriate records for the other application parameters it is possible to estimate this parameter. Table 5-9 presents an ancillary form suitable for documenting quantity of chemicals purchased and used.

Table 5-10 presents a similar form applicable to a watering control program. Special care must be taken to document the frequency of application. Again, complete records should be compiled with respect to individual roadway segments or storage areas. In some cases, relatively crude indirect estimates of frequency may be inferred from total mileage records for the spray truck. With appropriate equipment, elapsed operating time can easily be documented for stationary spray systems. As supplementary information, representative precipitation observations from a standard rain gause (0.01 in. increments) should be collected. Similarily, ambient temperature readings from a representative location, should also be recorded.

? only comment for dust suppression

Can determine from these two parameters!

TABLE 5-8. TYPICAL FORM FOR RECORDING CHEMICAL DUST SUPPRESSANT CONTROL PARAMETERS
(Sources: Unpaved roads, road shoulders, exposed areas, storage piles)

Date	Time	Type of chemical	~~Dilution ratio~~ gal chem	~~Application intensity~~ gal water (gal/yd^2)	Area(s) treated	Equipment used	Operator initials	Comments

TABLE 5-9. TYPICAL FORM FOR RECORDING DELIVERY OF CHEMICAL DUST SUPPRESSANTS

Date	Time	Chemical delivered	Quantity delivered	Delivery agent	Facility destination[a]	Comments

[a] Denote whether suppressant will be applied immediately upon receipt or placed in storage.

TABLE 5-10. TYPICAL FORM FOR RECORDING WATERING PROGRAM CONTROL PARAMETERS
(Sources: Unpaved roads, road shoulders, exposed areas, storage piles)

				Climatic parameters				
Date	Time	Application intensity (gal/yd^2)	Area(s) treated	Amb. temp. (°F)	Date/amt. of last rainfall	Equipment used	Operator initials	Comments

Table 5-11 presents a recordkeeping form for paved road control techniques (the types of information recorded are similar to that for unpaved road controls). Records should focus on frequency of surface cleaning and in the case of flushing, application intensity. Although not included, equipment maintenance forms may also be of value as they may indicate periods of time in which the equipment was unavailable, and thus not performing the expected control function.

Research conducted to date indicates that the control efficiency for roadway controls will depend upon traffic volume as well as predominant vehicle characteristics (i.e., weight and speed). For this reason it is recommended that periodic traffic counts and tabulations of vehicle type be undertaken for the various road segments being controlled. Counts may be accomplished by automatic counters, or as an alternative, short term (30 min to 1 hr) manual counts may also be taken (see Appendix C). In similar fashion, vehicle speed and average vehicle weight may also be ascertained.

5.3.3 Paved Surface Silt Loading

For paved surfaces, silt loading measurements may provide an appropriate indicator for monitoring the effectiveness of control programs. As indicated in Section 2, variations in silt loading have been shown to account for a considerable fraction of the variance in experimentally determined paved road emission factors.

One potentially feasible approach to paved road performance monitoring is based on comparison of a calculated emission factor (or equivalently emissions assuming constant ADT) using "the baseline" or uncontrolled state, to a calculated emission factor for the controlled (i.e., monitored) state. In both cases, these estimates are based on silt loading measurements collected by appropriate personnel. In order for this approach to work, standardized ~~sound~~ sampling/analysis protocols must be developed. The following discusses some of the requirements of a ~~sound~~ protocol for silt loading measurements. Possible problems that might be encountered in interpreting the calculations are also discussed.

TABLE 5-11. TYPICAL FORM FOR RECORDING PAVED ROAD/PARKING AREA CONTROL PARAMETERS
(Sources: Paved roads, parking areas, miscellaneous storage surfaces)

Date	Time	Treatment type (F, BS, VS, FBS)[a]	Area(s) treated	Amt. water applied (if used)	Equipment used	Operator initials	Comments

[a] F refers to flushing; BS refers to broom sweeping; VS refers to vacuum sweeping; FBS refers to flushing followed by broom sweeping.

The first requirement in applying this approach involves specification of a realistic baseline (or uncontrolled) silt loading value(s) for the surface of interest. At a minimum, the baseline value should reflect the influence of temporal variations such as occasional cleaning by rainfall, and increased loadings due to winter sanding. This specification should also consider spatial variations. For example, a single industrial facility is likely to exhibit a relatively wide range of baseline values, depending upon conditions such as: (1) vehicle mix and speed; (2) presence or absence of curbs; and (3) proximity to unpaved surfaces or industrial processes which serve as sources for surface loading (e.g., carryout).

An equally important consideration in using silt loading measurements as a monitoring tool, is the need to collect and analyze samples in a manner consistent with that outlined in Appendices A and B. The uncertainty associated with using loading values developed under different sampling and analysis (S/A) procedures is not known. However, the potential to systematically bias the calculations certainly exists if the S/A procedures used greatly differ from those documented in Appendices A and B.

A related requirement involves the need to estimate the uncertainties associated with the present S/A sampling technique. The reproducibility of the collection method is not well known particularly for the silt loading range typical of industrial facilities.

REFERENCES FOR SECTION 5.0

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APPENDIX A

PROCEDURES FOR SAMPLING SURFACE/BULK MATERIALS

APPENDIX A

PROCEDURES FOR SAMPLING OF SURFACE/BULK MATERIALS

The starting point for development of the recommended procedures for collection of road dust and aggregate material samples was a review of American Society of Testing and Materials (ASTM) Standards. When practical, the recommended procedures were structured identically to the ASTM standard. When this was not possible, an attempt was made to develop the procedure in a manner consistent with the intent of the majority of pertinent ASTM Standards.

A.1 UNPAVED ROADS

The main objective in sampling the surface material from an unpaved road is to collect a minimum gross sample of 23 kg (50 lb) for every 4.8 km (3 miles) of unpaved road. The incremental samples from unpaved roads should be distributed over the road segment, as shown in Figure A-1. At least four incremental samples should be collected and composited to form the gross sample.

The loose surface material is removed from the hard road base with a whisk broom and dustpan. The material should be swept carefully so that the fine dust is not injected into the atmosphere. The hard road base below the loose surface material should not be abraided so as to generate more fine material than exists on the road in its natural state.

Figure A-2 presents a data form to be used for the sampling of unpaved roads.

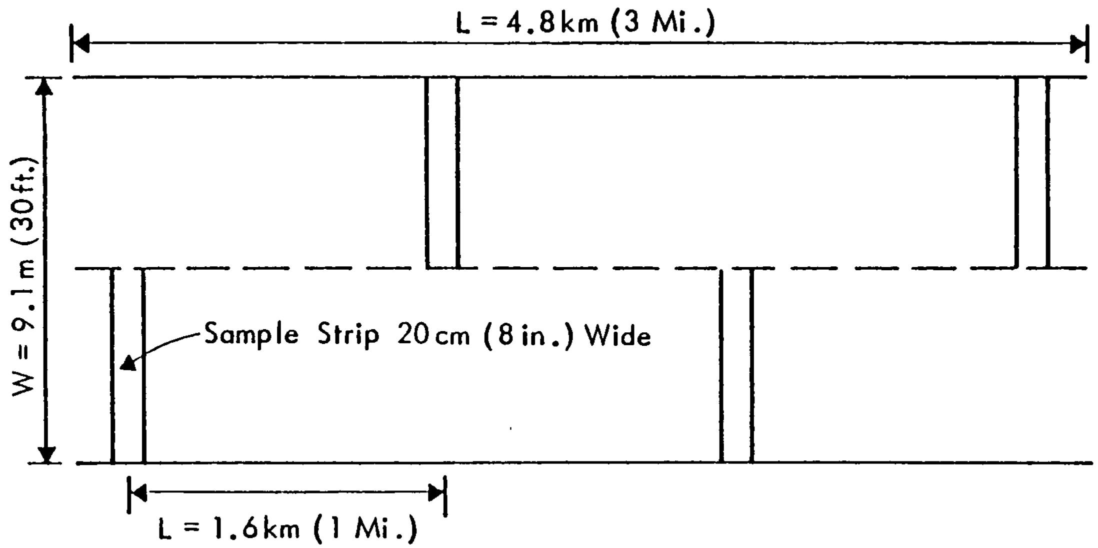


Figure A-1. Location of incremental sampling sites on an unpaved road.

SAMPLING DATA

Sample No. ______________

Unpaved Roads

Date ______________

Recorded by ______________

Type of Material Sampled: ______________

Site of Sampling: ______________

SAMPLING METHOD

1. Sampling device: whisk broom and dust pan
2. Sampling depth: loose surface material
3. Sample container: metal or plastic bucket with sealed poly liner
4. Gross sample specifications:
   (a) 1 sample of 23 kg (50 lb.) minimum for every 4.8 km (3 mi.) sampled
   (b) composite of 4 increments: lateral strips of 20 cm (8 in.) width extending over traveled portion of roadway half

Indicate deviations from above method: ______________

____

____

____

SAMPLING DATA

Sample No.	Time	Location	Surface Area	Depth	Quantity of Sample

DIAGRAM

Figure A-2. Sampling data form for unpaved roads.

A.2 PAVED ROADS

Ideally, for a given paved road, one gross sample per every 8 km (5 miles) of paved roads should be collected. For industrial roads, one gross sample should be obtained for each road segment in the plant. The gross sample should consist of at least two separate increments per travel lane. Thus, the gross sample collected from a four-lane roadway would consist of eight sample increments.

Figure A-3 presents a diagram showing the location of incremental samples for a four-lane road. Each incremental sample should consist of a lateral strip 0.3 to 3 m (1 to 10 ft) in width across a travel lane. The exact width is dependent on the amount of loose surface material on the paved roadway. For visually dirty road, a width of 0.3 m (1 ft) is sufficient; but for a visually clean road, a width of 3 m (10 ft) is needed to obtain an adequate sample.

The above sampling procedure may be considered as the preferred method of collecting surface dust from paved roadways. In many instances, however, the collection of eight sample increments may not be feasible due to manpower, equipment, and traffic/hazard limitations. As an alternative method, samples can be obtained from a single strip across all the travel lanes. When it is necessary to resort to this sampling strategy, care must be taken to select sites that have dust loading and traffic characteristics typical of the entire roadway segment of interest. In this situation, sampling from a strip 3 m to 9 m (10 to 30 ft) in width is suggested. From this width, sufficient sample can be collected, and a step toward representativeness in sample acquisition will be accomplished.

Samples are removed from the road surface by vacuuming, preceded by broom sweeping if large aggregate is present. The samples should be taken from the traveled portion of the lane with the area measured and recorded on the appropriate data form. With a whisk broom and a dust pan, the larger

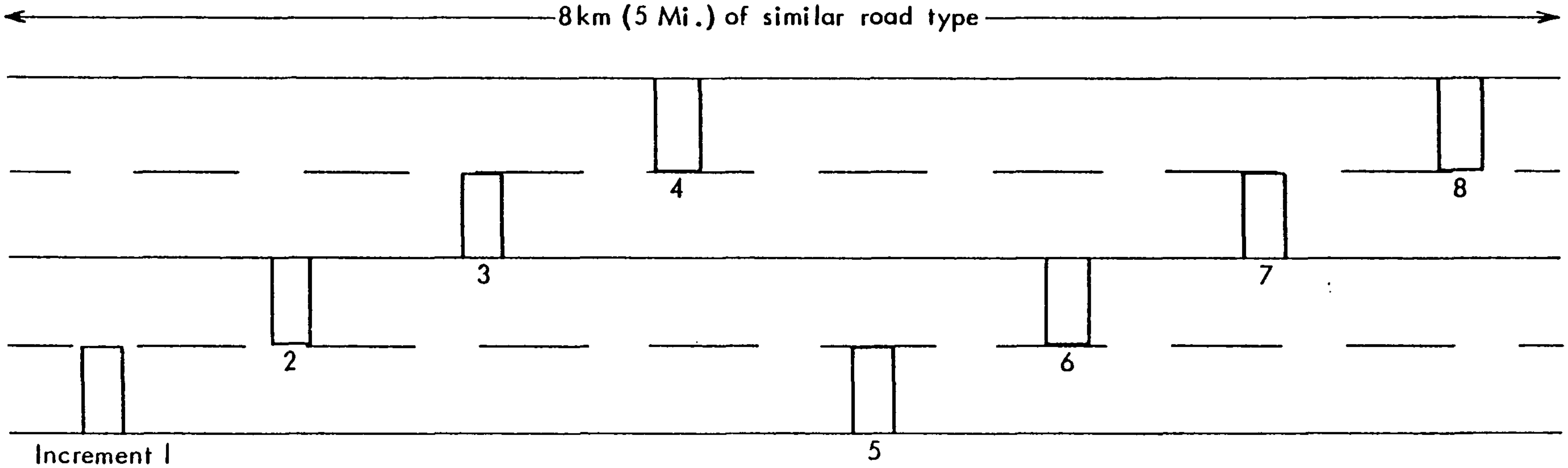


Figure A-3. Location of incremental sampling sites on a paved road.

particles are collected from the sampling area and placed in a clean, labeled container (plastic jar or bag). The remaining smaller particles are then swept from the road with a electric broom-type vacuum sweeper. The sweeper must be equipped with a preweighed, prelabeled, disposable vacuum bag. Care must be taken when installing the bags in the sweeper to avoid torn bags which can result in loss of sample. After the sample has been collected, the bag should be removed from the sweeper, checked for leaks and stored in a prelabeled, gummed envelope for transport. Figure A-4 presents a data form to be used for the sampling of paved roads.

Values for the dust loading on only the traveled portion of the roadway are needed for inclusion in the appropriate emission factor equation. Information pertaining to dust loading on curb/berm and parking areas is necessary in estimating carry-on potential to determine the appropriate Industrial Road Augmentation factor.

A.3 STORAGE PILES

In sampling the surface of a pile to determine representative properties for use in the wind erosion equation, a gross sample made up of top, middle, and bottom incremental samples should ideally be obtained since the wind disturbs the entire surface of the pile. However, it is impractical to climb to the top or even middle of most industrial storage piles because of the large size.

The most practical approach in sampling from large piles is to minimize the bias by sampling as near to the middle of the pile as practical and by selecting sampling locations in a random fashion. Incremental samples should be obtained along the entire perimeter of the pile. The spacing between the samples should be such that the entire pile perimeter is traversed with approximately equidistant incremental samples. If small piles are sampled, incremental samples should be collected from the top, middle, and bottom.

SAMPLING DATA

Paved Road Loading

Date ______________________ Recorded By ______________

Type of Material Sampled: ______________________

Site of Sampling: ______________ No. of Traffic Lanes ______________

Type of Pavement: Asphalt/Concrete Surface Condition ______________

SAMPLING METHOD

1. Sampling device: Portable vacuum cleaner (broom sweep first if loading is heavy)
2. Sampling depth: Loose surface material
3. Sample container: Metal or plastic bucket with sealed poly liner
4. Gross sample specifications:
   - (a) 1 sample within 100 m of the air sampling site
   - (b) composite of up to 3 increments: lateral strips of 1 m minimum width extending from curb to curb
   - (c) total sample weight of at least 4.5 Kg

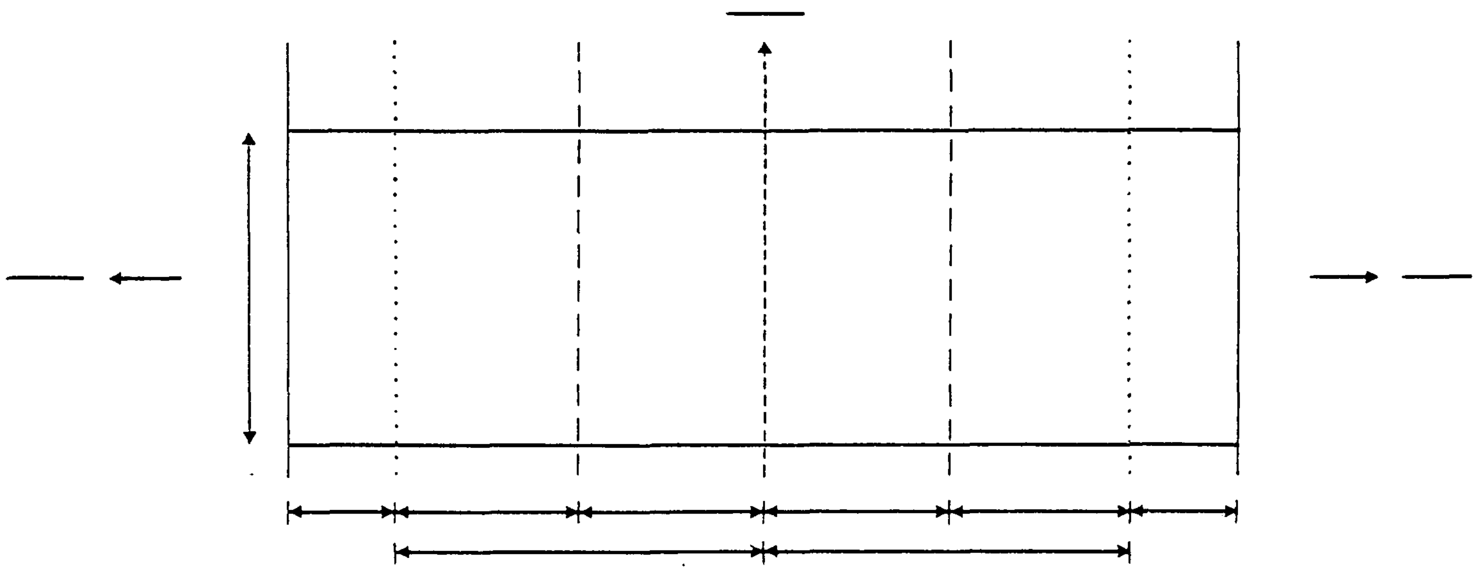
Indicate deviations from above method: ______________________

SAMPLING DATA

Sample No.	Vac Bag	Time	Surface Area	Quantity of Sample

Sample No.	Vac Bag	Time	Surface Area	Quantity of Sample

DIAGRAM



7/80

Figure A-4. Sampling data for paved roads.

An incremental sample (e.g., one shovelful) is collected by skimming the surface of the pile in a direction upward along the face. Every effort must be made by the person obtaining the sample not to purposely avoid sampling larger pieces of raw material. Figure A-5 presents a data form to be used for the sampling of storage piles.

In obtaining a gross sample for the purpose of characterizing a load-in or load-out process, incremental samples should be taken from the portion of the storage pile surface: (1) which has been formed by the addition of aggregate material or (2) from which aggregate material is being reclaimed.

SAMPLING DATA

Storage Piles

Sample No. ____________

Date ____________
Recorded by ____________

Type of Material Sampled: ____________

Site of Sampling: ____________

SAMPLING METHOD

1. Sampling device: pointed shovel
2. Sampling depth: 10 - 15 cm (4 - 6 inches)
3. Sample container: metal or plastic bucket with sealed poly liner
4. Gross sample specifications:
   (a) 1 sample of 23 kg (50 lb.) minimum for every pile sampled
   (b) composite of 10 increments
5. Minimum portion of stored material (at one site) to be sampled: 25%

Indicate deviations from above method: ____________

SAMPLING DATA

Sample No.	Time	Location (Refer to map)	Surface Area	Depth	Quantity of Sample

Figure A-5. Sampling data form for storage piles.

APPENDIX B

PROCEDURES FOR LABORATORY ANALYSIS OF SURFACE/BULK SAMPLES

APPENDIX B

PROCEDURES FOR LABORATORY ANALYSIS OF SURFACE/BULK SAMPLES

B.1 SAMPLES FROM SOURCES OTHER THAN PAVED ROADS

B.1.1 Sample Preparation

Once the 23 kg (50 lb) gross sample is brought to the laboratory, it must be prepared for silt analysis. This entails dividing the sample to a workable size.

A 23 kg (50 lb) gross sample can be divided by using: (1) mechanical devices; (2) alternate shovel method; (3) riffle; or (4) coning and quartering method. Mechanical division devices are not discussed in this section since they are not found in many laboratories. The alternate shovel method is actually only necessary for samples weighing hundreds of pounds. Therefore, this appendix discusses only the use of the riffle and the coning and quartering method.

ASTM Standards describe the selection of the correct riffle size and the correct use of the riffle. Riffle slot widths should be at least three times the size of the largest aggregate in the material being divided. The following quote describes the use of the riffle:[1]

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[1] D2013-72. Standard Method of Preparing Coal Samples for Analysis. Annual Book of ASTM Standards, 1977.

"Divide the gross sample by using a riffle. Riffles properly used will reduce sample variability but cannot eliminate it. Riffles are shown in Figure B-1, (a) and (b). Pass the material through the riffle from a feed scoop, feed bucket, or riffle pan having a lip or opening the full length of the riffle. When using any of the above containers to feed the riffle, spread the material evenly in the container, raise the container, and hold it with its front edge resting on top of the feed chute, then slowly tilt it so that the material flows in a uniform stream through the hopper straight down over the center of the riffle into all the slots, thence into the riffle pans, one-half of the sample being collected in a pan. Under no circumstances shovel the sample into the riffle, or dribble into the riffle from a small-mouthed container. Do not allow the material to build up in or above the riffle slots. If it does not flow freely through the slots, shake or vibrate the riffle to facilitate even flow."

The procedure for coning and quartering is best illustrated in Figure B-2. The following is a description of the procedure: (1) mix the material and shovel it into a neat cone; (2) flatten the cone by pressing the top without further mixing; (3) divide the flat circular pile into equal quarters by cutting or scraping out two diameters at right angles; (4) discard two opposite quarters; (5) thoroughly mix the two remaining quarters, shovel them into a cone, and repeat the quartering and discarding procedures until the sample has been reduced to 0.9 to 1.8 kg (2 to 4 lb). Samples likely to be affected by moisture or drying must be handled rapidly, preferably in an area with a controlled atmosphere, and sealed in a container to prevent further changes during transportation and storage. Care must be taken that the material is not contaminated by anything on the floor or that a portion is not lost through cracks or holes. Preferably, the coning and quartering operation should be conducted on a floor covered with clean paper. Coning and quartering is a simple procedure which is applicable to all powdered materials and to sample sizes ranging from a few grams to several hundred pounds.[2]

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2 Silverman, L., et al., Particle Size Analysis in Industrial Hygiene, Academic Press, New York, 1971.

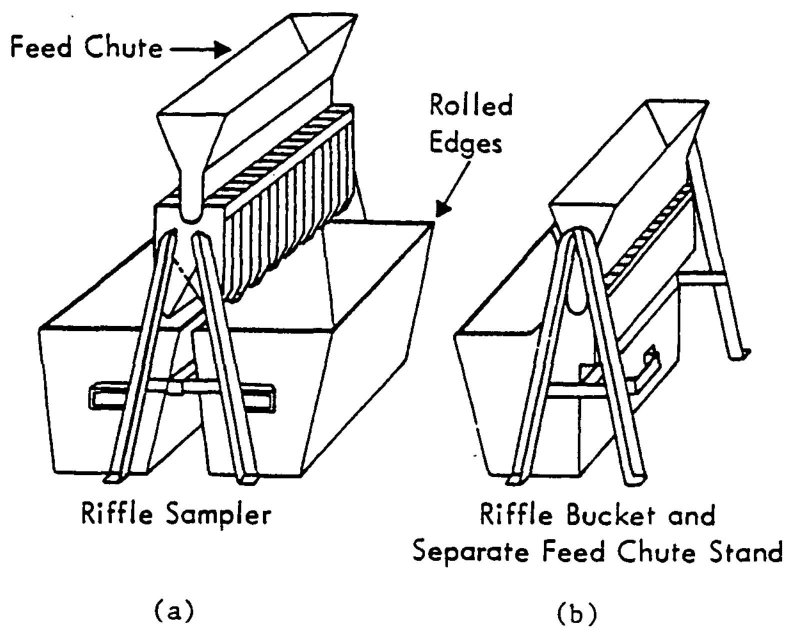

Figure B-1. Sample dividers (riffles).

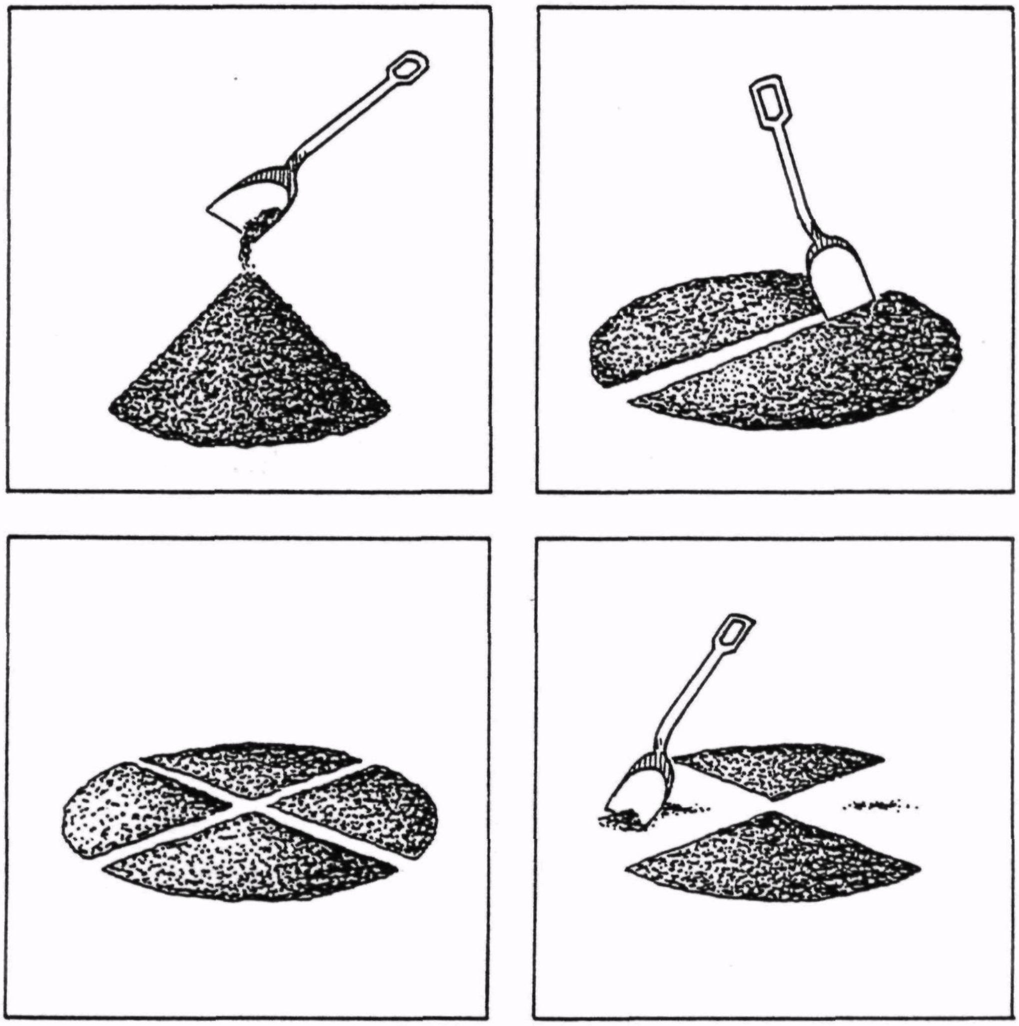

Figure B-2. Coning and quartering.

The size of the laboratory sample is important--too little sample will not be representative and too much sample will be unwieldy. Ideally, one would like to analyze the entire gross sample in batches, but this is not practical. While all ASTM Standards ackhowledge this impracticality, they disagree on the exact size, as indicated by the range of recommended samples, extending from 0.05 to 27 kg (0.1 to 60 lb).

The main principle in sizing the laboratory sample is to have sufficient coarse and fine portions to be representative of the material and to allow sufficient mass on each sieve so that the weighing is accurate. A recommended rule of thumb is to have twice as much coarse sample as fine sample. A laboratory sample of 800 to 1,600 g is recommended since that is the largest quantity that can be handled by the scales normally available (1,600-g capacity). Also, more sample than this can produce screen clogging for the 8 in. diameter screens normally available.

B.1.2 Laboratory Analysis of Samples for Silt Content

The basic recommended procedure for silt analysis is mechanical, dry sieving. A step-by-step procedure is given in Table B-1. The sample should be oven dried for 24 hr at 230°F before sieving. The sieving time is variable; sieving should be continued until the net sample weight collected in the pan increases by less than 3.0% of the previous net sample weight collected in the pan. A minor variation of 3.0% is allowed since some sample grinding due to inter-particle abrasion will occur, and consequently, the weight will continue to increase. When the change reduces to 3.0%, it is thought that the natural silt has been passed through the No. 200 sieve screen and that any additional increase is due to grinding.

Both the sample preparation operations and the sieving results can be recorded on Figure B-3.

TABLE B-1. SILT ANALYSIS PROCEDURES

1. Select the appropriate 8-in. diameter, 2-in. deep sieve sizes. Recommended U.S. Standard Series sizes are: 3/8 in., No. 4, No. 20, No. 40, No. 100, No. 140, No. 200, and a pan. Comparable Tyler Series sizes can also be utilized. The No. 20 and the No. 200 are mandatory. The others can be varied if the recommended sieves are not available or if buildup on one particular sieve during sieving indicates that an intermediate sieve should be inserted.

2. Obtain a mechanical sieving device such as a vibratory shaker or a Roto-Tap.

3. Clean the sieves with compressed air and/or a soft brush. Material lodged in the sieve openings or adhering to the sides of the sieve should be removed (if possible) without handling the screen roughly.

4. Obtain a scale (capacity of at least 1,600 g) and record make, capacity, smallest division, date of last calibration, and accuracy (if available).

5. Tare sieves and pan. Check the zero before every weighing. Record weights.

6. After nesting the sieves in decreasing order with pan at the bottom, dump dried laboratory sample (probably immediately after moisture analysis) into the top sieve. Brush fine material adhering to the sides of the container into the top sieve and cover the top sieve with a special lid normally purchased with the pan.

7. Place nested sieves into the mechanical device and sieve for 20 min. Remove pan containing minus No. 200 and weigh. Replace pan beneath the sieves and sieve for another 10 min. Remove pan and weigh. When the difference between two successive pan sample weighings (where the tare of the pan has been subtracted) is less than 3.0%, the sieving is complete.

8. Weigh each sieve and its contents and record the weight. Check the zero before every weighing.

9. Collect the laboratory sample and place the sample in a separate container if further analysis is expected.

SILT ANALYSIS

Date ____________________ Recorded By ____________________

Sample No: ____________________

Material: ____________________

Split Sample Balance:

Make ____________________

Capacity ____________________

Smallest Division ____________________

Material Weight (after drying)

Pan + Material: ____________________

Pan: ____________________

Dry Sample: ____________________

Final Weight: ____________________

$$\% \text{ Silt} = \frac{\text{Net Weight} < 200 \text{ Mesh}}{\text{Total Net Weight}} \times 100 = \_\_\_\_\_ \%$$

SIEVING

Time: Start:	Weight (Pan Only)
Initial (Tare):	
10 min:	
20 min:	
30 min:	
40 min:	

SIZE DISTRIBUTION

Screen	Tare Weight (Screen)	Final Weight (Screen + Sample)	Net Weight (Sample)	%
3/8 in.				
4 mesh				
10 mesh				
20 mesh				
40 mesh				
100 mesh				
140 mesh				
200 mesh				
Pan				

Comments:

Figure B-3. Form for recording sample preparation operations and sieving results.

B.2 SAMPLES FROM PAVED ROADS

B.2.1 Sample Preparation and Analysis for Total Loading

The gross sample of paved road dust will arrive at the laboratory in two types of containers: (1) the broom swept dust will be in plastic bags; and (2) the vacuum swept dust will be in vacuum bags.

Both the broom swept dust and the vacuum swept dust are weighed on a beam balance. The broom swept dust is weighed in a tared container. The vacuum swept dust is weighed in the vacuum bag which was tared and equilibrated in the laboratory before going to the field. The vacuum bag and its contents should be equilibrated again in the laboratory before weighing.

The total surface dust loading on the traveled lanes of the paved road is then calculated in units of kilograms of dust on the traveled lanes per kilometer of road. When only one strip of length is taken across the traveled lanes, the total dust loading on the traveled lanes is calculated as follows:

$$L = \frac{m_b + m_v}{\ell} \qquad \text{(B-1)}$$

where
L = Total dust loading (kg/km)
m_b = mass of the broom swept dust (kg)
m_v = mass of the vacuum swept dust (kg)
ℓ = length of strip as measured along the centerline of the road (km)

When several incremental samples are collected on alternate roadway halves as shown in Figure A-3, the total surface dust loading is calculated as follows:

$$L = \frac{m_{b1} + m_{v1} + m_{b5} + m_{v5}}{\ell_1 + \ell_5} + \frac{m_{b2} + m_{v2} + m_{b6} + m_{v6}}{\ell_2 + \ell_6} + \frac{m_{b3} + m_{v3} + m_{b5} + m_{v7}}{\ell_3 + \ell_7} + \frac{m_{b4} + m_{v4} + m_{b8} + m_{v8}}{\ell_4 + \ell_8} + \qquad \text{(B-2)}$$

L = Total dust loading (kg/km)

where m_{b_i} = mass of broom sweepings for increment i (kg)

m_{v_i} = mass of vacuum sweepings for increment i (kg)

ℓ_i = length of increment i as measured along the road centerline (km)

B.2.2 Sample Preparation and Analyses for Road Dust Silt Content

After weighing the sample to calculate total surface dust loading on the traveled lanes, the broom swept and vacuum swept dust is composited. The composited sample is usually small and requires no sample splitting in preparation for sieving. If splitting is necessary to prepare a laboratory sample of 800 to 1,600 g, the techniques discussed in Section B.1.1 can be used. The laboratory sample is then sieved using the techniques described in Section B.1.2.

APPENDIX C

PROCEDURES FOR QUANTIFICATION OF TRAFFIC CHARACTERISTICS

APPENDIX C

PROCEDURES FOR QUANTIFICATION OF TRAFFIC CHARACTERISTICS

From Section 2.1 of the body of this report, it is apparent that traffic characteristics must be quantified along with road surface dust in order to utilize the emission factor equations. The following sections provide data collection techniques and forms for the quantification of traffic characteristics such as number of vehicles by type (vehicle mix), vehicle speed, weight, number of wheels, number of travel lanes and percent of traffic riding on the road berms.

C.1 VEHICLE SPEED

There are two ways to measure vehicle speed in the field: (1) radar guns; and (2) stop-watch timing between two markers. The sampling period should be 15 to 30 min for each site where a gross sample of road surface material was collected.

C.2 VEHICLE MIX

The vehicle mix is performed by a observer in the field. The mix categorizes vehicles passing the observation point by type, weight, and number of wheels. The total vehicle count divided by the observation period gives the traffic density for that period. It is important that the observer identify whether haul or dump trucks are loaded or unloaded. Figure C-1 provides the form used to tabulate vehicle mix data. Vehicle mix should be determined at the sites where gross samples of road surface material were collected. The sampling period should be 15 to 30 min for each site chosen.

VEHICLE MIX

Sample No. ____________ Date ____________

Recorded by ____________

Road Location: ____

Road Type: ____

Sampling Start Time: ______________ Stop Time: ______________

Vehicle Type/Wt.	Axles/Wheels	1	2	3	4	5	6	7	8	9	10	Total
Cars, Vans & Pickups	2/4											
Dump trucks (loaded)	3/10											
Dump trucks (unloaded)	3/10											
Haul trucks (loaded)	2/6											
Haul trucks (unloaded)	2/6											
Tractor-trailers	5/18											
Tractor-trailers	4/14											
	/											
	/											
	/											
	/											
	/											
	/											

Figure C-1. Vehicle mix data form.

For industrial roads, it is important to meet with plant personnel to identify the manufacturer and model of heavy-duty vehicles such as haul trucks so that reliable weights can be determined. For example, Euclid R-35, R-50, and R-85 weigh 29, 43, and 56 tons unloaded, respectively.

If emission rates are to be determined, the vehicle mixes do provide a total vehicle count over the 15 to 30 min sampling period, but it is better to place an automatic traffic counter at the site for a 24-hr period. The automatic traffic counters allow a much more representative sampling time (24-hr) while requiring a minimum amount of personnel hours in the field.

C.3 NUMBER OF LANES TRAVELED BY VEHICLES

The observer at each site should identify the number of travel lanes. This will equal the total number of lanes minus the parking lanes. At industrial sites, the number of parking lanes will often be zero and the travel lanes will equal the total number of lanes.

C.4 QUANTIFICATION OF TRAVEL ON ROAD BERM

For vehicle traffic on paved roads, the existence of vehicle traffic on unpaved berms is important to quantify. This situation can occur when, for example, two large haul trucks traveling in opposite directions pass on a two lane paved road. One or both the trucks are often forced to travel with one set of wheels on the berm. If the berm is unpaved, this could result in increased emissions. Even if the berm is paved, an increase in emissions may occur because of loose dust accumulations. The field observer should record the nature of the berm, i.e., paved (clean or dirty) or unpaved, and the percentage of vehicles traveling on the berm. Figure C-1 could be used for this purpose. For example, simply circling the symbol used to indicate a vehicle pass could indicate that the vehicle traveled on the berm of the road. Based on the percentage of traffic on paved roads traveling on an unpaved berm, the industrial road augmentation factor (I) can be determined from Figure C-2.

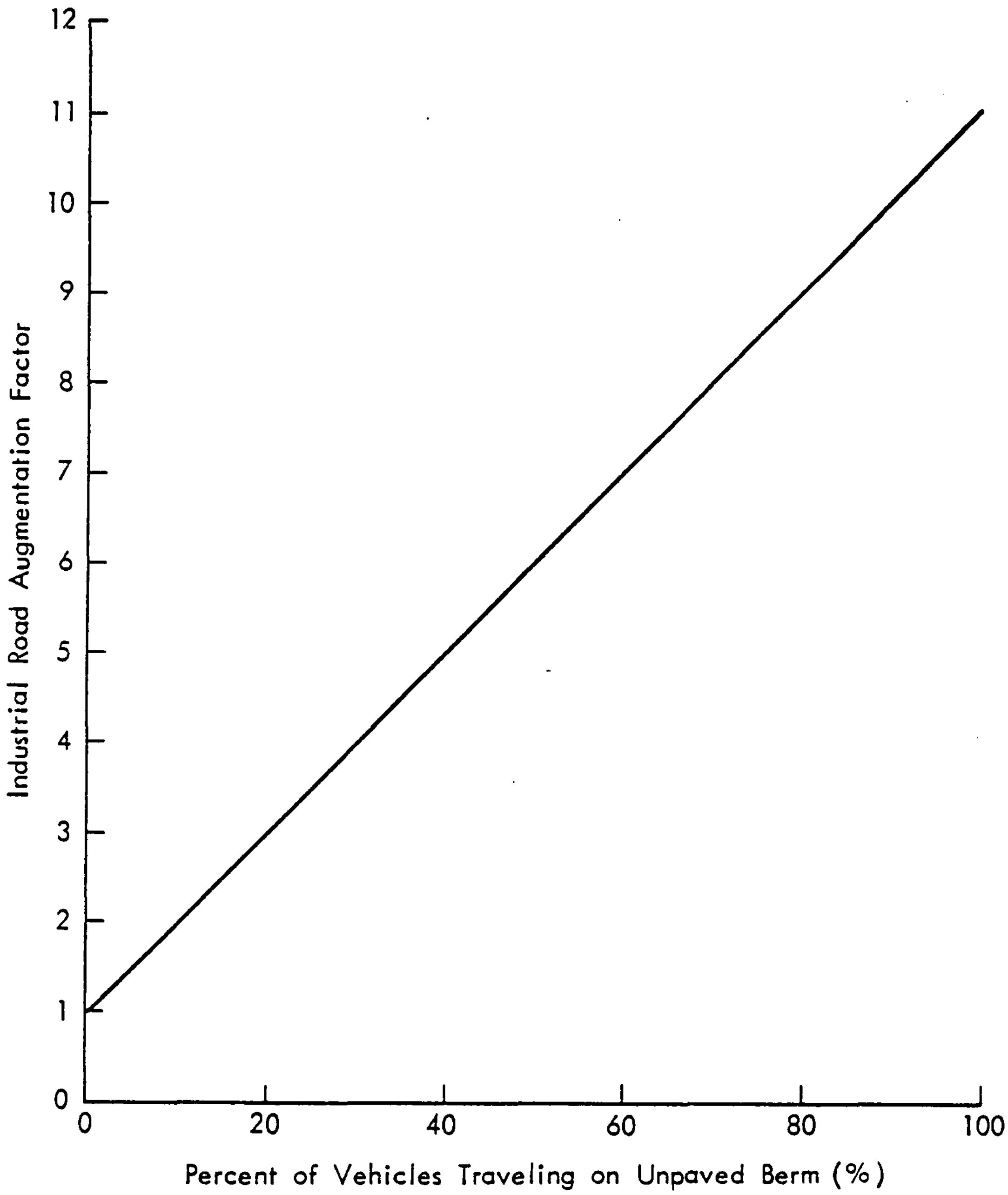

Figure C-2. Determination of industrial road augmentation factor.