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ASPHALTIC CONCRETE INDUSTRY
PARTICULATE EMISSIONS:
SOURCE CATEGORY REPORT

Prepared for

Office of Air Quality Planning and Standards

Prepared by

Air and Energy Engineering Research
Laboratory
Research Triangle Park NC 27711

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ASPHALTIC CONCRETE INDUSTRY PARTICULATE EMISSIONS: SOURCE CATEGORY REPORT

by

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PREFACE

This report was prepared by Midwest Research Institute (MRI) for the Environmental Protection Agency's (EPA's) Air and Energy Engineering Research Laboratory under EPA Contract No. 68-02-3158, Technical Directive No. 18. Dale Harmon was the Project Officer for this study. The work was performed in MRI's Air Quality Assessment Section (Chatten Cowherd, Head). The report was authored by John Kinsey. Gregory Muleski was responsible for the computer software used in the study, and Julia Poythress was involved in data compilation and analysis.

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1.0 INTRODUCTION

The U.S. Environmental Protection Agency (EPA) is in the process of reviewing the pertinent technical criteria and data bases to determine whether the establishment of a revised National Ambient Air Quality Standard (NAAQS) for particulate matter based on particle size is warranted. Upon adoption of such a standard, the Clean Air Act requires that each state develop and submit revisions to their State Implementation Plan (SIP) which outline how they will attain and maintain the standard. These revisions to the SIP would necessitate the collection and use of information related to size-selective particulate emissions from new and existing sources. Thus, a need exists to initiate development of an emission factor data base to meet such objectives.

Since 1972 the document entitled "Compilation of Air Pollutant Emission Factors" (AP-42) has been published by the EPA. This document contains a compendium of emission factor reports for the most significant emission source categories. Supplements to AP-42 have been published both for new source categories and for updating existing emission factors as more information about sources and the control of emissions has become available. Up to this point, however, little information has been provided in AP-42 with regard to particle size characteristics of particulate emissions.

To address the requirement for size-specific emission factors, the EPA is currently conducting research to characterize the emissions of fine particles in the inhalable particulate (IP) size range for a variety of industrial sources. The purpose of this research is to develop emission factors to be used if revisions to the National Ambient Air Quality Standard for particulate matter are made to address fine particles. As part of this program, Midwest Research Institute (MRI) has prepared this report which reviews the existing emission data base for asphalt concrete* plants based on particle size and provides a revised AP-42 Section (8.1) for that industry category. Included in the revised Section 8.1 are the available size-specific emission factors for asphalt concrete plants presented according to the type of process and control technology used.

This report is organized by section as follows:

Section 2.0 - Industry Description
Section 3.0 - Data Review and Emission Factor Development
Section 4.0 - Chemical Characterization
Section 5.0 - Proposed AP-42 Section
Section 6.0 - References

* The term "asphalt concrete" is used everywhere in this report except for the proposed AP-42 section where "asphaltic concrete" has been substituted. Asphalt concrete is the term most commonly accepted by experts working in the industry.

2.0 INDUSTRY DESCRIPTION

Asphalt paving (concrete) consists of a mixture of well graded, high quality aggregate and liquid asphalt cement which is heated and mixed in measured quantities to produce bituminous pavement materials.[1] Hot mix asphalt paving can be manufactured by any of the following basic processes: batch-mix, continuous-mix, and drum-mix.

In this section, the raw material used in the formulation of asphalt concrete is described, along with the basic processes available for its production and the technology employed by the industry to control particulate emissions.

2.1 RAW MATERIAL

2.1.1 Asphalt Cement

Asphalt is a dark brown to black thermoplastic cementitious material composed principally of bitumens which come either from naturally occurring deposits or is derived from crude petroleum. Chemically, asphalt is a hydrocarbon consisting of asphaltenes (small particles surrounded by a resin coating), resins, and oils. The asphaltenes contribute to body, the resins furnish the adhesive and ductile properties, and the oil influences the viscosity and flow characteristics of the asphalt.[2]

Asphalt cement is a highly viscous material available in many standard grades.[3] Originally, penetration tests were used to specify grades of asphalt cement. More recently, viscosity is becoming the standard characteristic to specify grades.[3] Specifications for asphalt cement are based on a range of viscosity at a reference temperature of 60°C (140°F). A minimum viscosity at 135°C (275°F) is also specified. These temperatures were chosen because 60°C (140°F) approximates the maximum temperature of asphalt pavement surfaces in the United States while 135°C (275°F) approximates mixing and laydown temperatures for hot mix asphalt pavements. Specifications for the various grades of asphalt cement are presented in Table 2-1.[3]

In some areas, emulsified asphalts are used for the production of hot mix paving. Emulsified asphalts are dispersions of colloidal size globules of asphalt in water (or visa versa) that are prepared using high speed mixers or colloid mills. Small quantities of surface active agents or emulsifiers are added to the asphalt to aid dispersion. Anionic and cationic emulsified asphalts are two commercially available asphalt emulsions.[1] Specifications for the various grades of emulsified asphalts are presented in Table 2-2.[3]

TABLE 2-1. SPECIFICATIONS FOR ASPHALT CEMENTS[3]

Characteristics	AASHTO[a] test method	ASTM[b] test method	Grades				
			Industrial and special	Paving			
Penetration, 77°F, 100 g, 5 sec.	T49	D 5	40-50	60-70	85-100	120-150	200-300
Viscosity at 275°F							
Saybolt Furol, SSF	-	E 102	120+	100+	85+	70+	50+
Kinematic, Centistokes	-	D 445	240+	200+	170+	140+	100+
Flash point (Cleveland Open Cup), °F	T 48	D 92	450+	450+	450+	425+	350+
Thin film oven test	T 179	-	-	-	-	-	-
Penetration after test, 77°F 100 g, 5 sec., % of original	T 49	D 5	52+	50+	45+	42+	37+
Ductility:							
At 77°F, cm	T 51	D 113	100+	100+	100+	60+	-
At 60°F, cm			-	-	-	-	60+
Solubility in carbon tetrachloride,[d] %	T 44[c]	D 4[c]	99.5+	99.5+	99.5+	99.5+	99.5+
General requirements			The asphalt shall be prepared by the refining of petroleum. It shall be uniform in character and shall not foam when heated to 350°F.				

a American Association of State Highway Transportation Organizations.
b American Society of Testing & Materials.
c Except that carbon tetrachloride is used instead of carbon disulfide as solvent. Method No. 1 in AASHTO Method T 44 or Procedure No. 1 in ASTM Method D 4.
d This solvent is being reevaluated for replacement due to its toxic and carcinogenic properties.

TABLE 2-2. SPECIFICATIONS FOR EMULSIFIED ASPHALTS[3]

Characteristics	AASHTO[a] test method	ASTM[b] test method	Rapid settling RS-1	Rapid settling RS-2	Medium settling MS-2	Slow settling SS-1
Tests on Emulsion						
Fural viscosity at 77°F, sec.			20-100	-	100+	20-100
Fural viscosity at 122°F, sec.			-	75-400	-	-
Residue from distallation, %			57-62	62-69	62-69	57-62
Settlement, 5 days, %			3-	3-	3-	3-
	T 59	D 244				
Demulsibility:						
35 ml of 0.02 N $CaCl_2$, %			60+	50+	-	-
50 ml of 0.10 N $CaCl_2$, %			-	-	30-	-
Sieve test (retained on No. 20), %			0.10-	0.10-	0.10-	0.10-
Cement mixing test, %			-	-	-	2.0-
Tests on Residue						
Penetration, 77°F, 100 g, 5 sec.	T 49[d]	D 5[d]	100-200	100-200	100-200	100-200[c]
Solubility in carbon tetrachloride,[e] %	T 44[d]	D 4[d]	97.5+	97.5+	97.5+	97.5+
Ductility, 77°F, cm.	T 51	D 113	40+	40+	40+	40+

[a] American Association of State Highway Transporation Organizations.
[b] American Society of Testing & Materials.
[c] For some special uses, such as dilute Emulsified Asphalt fog seal coats, a lower penetration residue may by preferable. In such cases, the Penetration of Residue at 77°F shall be 40-90 and the grade shall be designated as SS-1h.
[d] Except that carbon tetrachloride is used instead of carbon disulfide as solvent, Method No. 1 in AASHO Method T 44 or Procedure No. 1 in ASTM Method D 4.
[e] This solvent is being reevaluated for replacement due to its toxic and carcinogenic properties.

2.1.2 Aggregate

Asphalt pavement mixtures are produced by combining mineral aggregates and asphalt cement. Aggregates constitute over 92% of the total mixture.[2] Aside from the amount and grade of asphalt used, mix characteristics are determined by the relative amounts and types of aggregate used.

Aggregate is generally sized in three groups: coarse aggregate (material > 2.36 mm), fine aggregate (material passing < 2.36 mm), and mineral filler (material < 74 μm).[1] Coarse aggregate can consist of crushed stone, limestone, gravel, slag from steel mills, glass, oyster shells, and material such as decomposed granite (or other fractured material), or highly angular material with a pitted or rough surface. Fine aggregate consists of natural sand, crushed limestone, slag, or gravel or any mixture of these materials. Mineral filler or mineral dust consists of crushed rock, limestone, hydrated lime, portland cement, fly ash, or other nonplastic mineral matter which is either added to the mix or is indigenous to the aggregate itself. A minimum of 70% of this material must pass through a 74-μm sieve.[1] All aggregate should be free of clay and silt. Table 2-3 lists the composition for the various types of asphalt paving mixtures specified by the American Society of Testing and Materials (ASTM) Designation 3515.[1]

Generally, a single natural source cannot provide the required gradation; thus, the mechanical combination of two or more aggregates is often necessary. Aggregates may also be blended because of limited supplies, for economic reasons, and to control particulate emissions. Blending techniques include trial and error, mathematical, and graphical blending methods.[4]

State transportation departments are usually responsible for specifying the percentage of each aggregate size in a given mix. State and local specifications for aggregate properties which are required for a sound mix take into account variations in locally available supplies.[4,5] In practice, the plant operator develops a job-mix formula to produce the particular grade of paving material necessary to meet customer specifications based on the characteristics of the available aggregate.

2.2 PROCESS DESCRIPTION

2.2.1 Batch-Mix Process

Crushed and screened raw aggregate is stockpiled near the plant where the moisture content will stabilize between 3 and 5% moisture by weight for the total aggregate blend (fine aggregate contains the highest amount of moisture).[6] The aggregate is transferred by front-end loader from the storage piles and placed in the appropriate hoppers of the cold feed unit. The material is metered from the hoppers onto a moving belt and conveyed by bucket elevator or belt conveyor into a direct-fired rotary dryer fueled by gas or oil, or lately by coal or coal/oil slurries.

The dryer is a revolving cylinder usually ranging from 0.9 to 3.5 m (3 to 12 ft) in diameter and from 4.5 to 12 m (15 to 40 ft) long, in which aggregate is dried and heated by an oil, gas, or combination oil-gas burner.

TABLE 2-3. COMPOSITION OF ASPHALT PAVING MIXTURES

Sieve Size	Asphalt Concrete					Sand Asphalt	Sheet Asphalt
	Mix Designation and Nominal Maximum Size of Aggregate						
	1½ in. (2A) (37.5 mm)	1 in. (3A) (25.0 mm)	¾ in. (4A) (19.0 mm)	½ in. (5A) (12.5 mm)	⅜ in. (6A) (9.5 mm)	No. 4 (7A) (4.75 mm)	No. 16 (8A) (1.18 mm)
	Grading of Total Aggregate (Coarse Plus Fine, Plus Filler if Required) Amounts Finer Than Each Laboratory Sieve (Square Opening), weight percent						
2½ in. (63 mm)	...	...	...	...	...	...	...
2 in. (50 mm)	100	...	...	...	...	...	...
1½ in. (37.5 mm)	90 to 100	100	...	...	...	...	...
1 in. (25.0 mm)	...	90 to 100	100	...	...	...	...
¾ in. (19.0 mm)	60 to 80	...	90 to 100	100	...	...	...
½ in. (12.5 mm)	...	60 to 80	...	90 to 100	100	...	...
⅜ in. (9.5 mm)	...	...	60 to 80	...	90 to 100	100	...
No. 4 (4.75 mm)	20 to 55	25 to 60	35 to 65	45 to 70	60 to 80	80 to 100	100
No. 8[a] (2.36 mm)	10 to 40	15 to 45	20 to 50	25 to 55	35 to 65	65 to 100	95 to 100
No. 16 (1.18 mm)	...	...	...	...	...	40 to 80	85 to 100
No. 30 (600 μm)	...	...	...	...	...	20 to 65	70 to 95
No. 50 (300 μm)	2 to 16	3 to 18	3 to 20	5 to 20	6 to 25	7 to 40	45 to 75
No. 100 (150 μm)	...	...	...	...	...	3 to 20	20 to 40
No. 200[b] (75 μm)	0 to 5	1 to 7	2 to 8	2 to 9	2 to 10	2 to 10	9 to 20
	Asphalt Cement, weight percent of Total Mixture[c]						
	3½ to 8	4 to 8½	4 to 9	4½ to 9½	5 to 10	7 to 12	8½ to 12
	Suggested Coarse Aggregate Sizes						
	4 and 67	5 and 7 or 57	67 or 68 or 6 and 8	7 or 78	8		

[a]In considering the total grading characteristics of an asphalt paving mixture the amount passing the No. 8 (2.36 mm) sieve is a significant and convenient field control point between fine and coarse aggregate. Gradings approaching the maximum amount permitted to pass the No. 8 (2.36-mm) sieve will result in pavement surfaces having comparatively fine texture, while gradings approaching the minimum amount passing the No. 8 (2.36-mm) sieve will result in surfaces with comparatively coarse texture.

[b]The material passing the No. 200 (75-μm) sieve may consist of fine particles of the aggregates or mineral filler, or both. It shall be free from organic matter and clay particles and have a plasticity index not greater than 4 when tested in accordance with Method D423 and Method D424.

[c]The quantity of asphalt cement is given in terms of weight percent of the total mixture. The wide difference in the specific gravity of various aggregates, as well as a considerable difference in absorption, results in a comparatively wide range in the limiting amount of asphalt cement specified. The amount of asphalt required for a given mixture should be determined by appropriate laboratory testing or on the basis of past experience with similar mixtures, or by a combination of both.

*U.S.A. Standard sieve designation is 38.1 mm.

The cylinder is equipped with longitudinal troughs or channels called "flights" that lift the aggregate and drop it in veils through the hot gases. The slope of the cylinder, its rotation speed, diameter, length, and the arrangement and number of flights control the length of time required for the aggregate to pass through the dryer (residence time). The dryer performs two functions; it vaporizes and removes the moisture, and it heats the aggregate to mixing temperature.

The most commonly used oil burner in dryers atomizes the fuel oil with low pressure air. There are also medium and high pressure gas burners, combination oil and gas burners, and liquid petroleum gas (LPG) burners.

As it leaves the dryer, the material drops onto a bucket elevator and is transferred to a set of vibrating screens where it is classified by size into four or more grades. The classified aggregate then drops into four or more large bins. The bins provide a substantial amount of surge capacity for the dryer system. The operator controls the aggregate size distribution by opening one of the bins and allowing the classified aggregate to be deposited into a weigh hopper until the desired amount of material is obtained. The doors of this bin are then closed, another bin is opened, and so on. After all the material is weighed out, the mixture is dropped into a pugmill mixer and mixed (usually dry) for about 15 sec. The action of the two-shafted pugmill is similar to that of an egg beater except that the paddles are mounted on horizontal shafts instead of vertically. The asphalt cement is pumped from a heated storage tank (or tanks) into the pugmill and thoroughly mixed with the aggregate for 25 to 60 sec to form asphalt concrete. The hot mix is then deposited in a truck and hauled away to the job site. A flow diagram of the batch-mix process is shown in Figure 2-1.[6]

As with most facilities in the mineral products industry, asphalt batch plants have two major categories of particulate emissions: those which are vented to the atmosphere through some type of stack, vent, or pipe (ducted sources) and those which are emitted directly from the source to the ambient air (fugitive sources) without the aid of such equipment. Ducted emissions are usually captured and transported by an industrial ventilation system with one or more fans or air movers and emitted to the atmosphere through a stack. Fugitive sources, on the other hand, can either be process fugitives, which are emissions associated with some form of physical or chemical change in the material being processed, or open dust sources where no such change occurs.

The most significant source of ducted emissions from asphalt batch plants is the rotary dryer. The amount of aggregate dust carried out of the dryer by the moving gas stream depends upon a number of factors, including the gas velocity in the drum, the particle size distribution of the aggregate, and the specific gravity and aerodynamic characteristics of the particles. The most significant of these factors is the gas velocity in the dryer.[6] Figures 2-2 and 2-3 show the effect of increasing dryer gas velocity upon production capacity and dust carryout as determined by a study conducted by the Barber-Greene Company.[6,7] It should be noted that a 50% increase in gas velocity will allow about a 30% increase in production while causing a 150% increase in dust carryout. Of course the increase in drum velocity also results in higher air volumes drawn through the dryer which subsequently increases the amount of oxygen available for combuston.

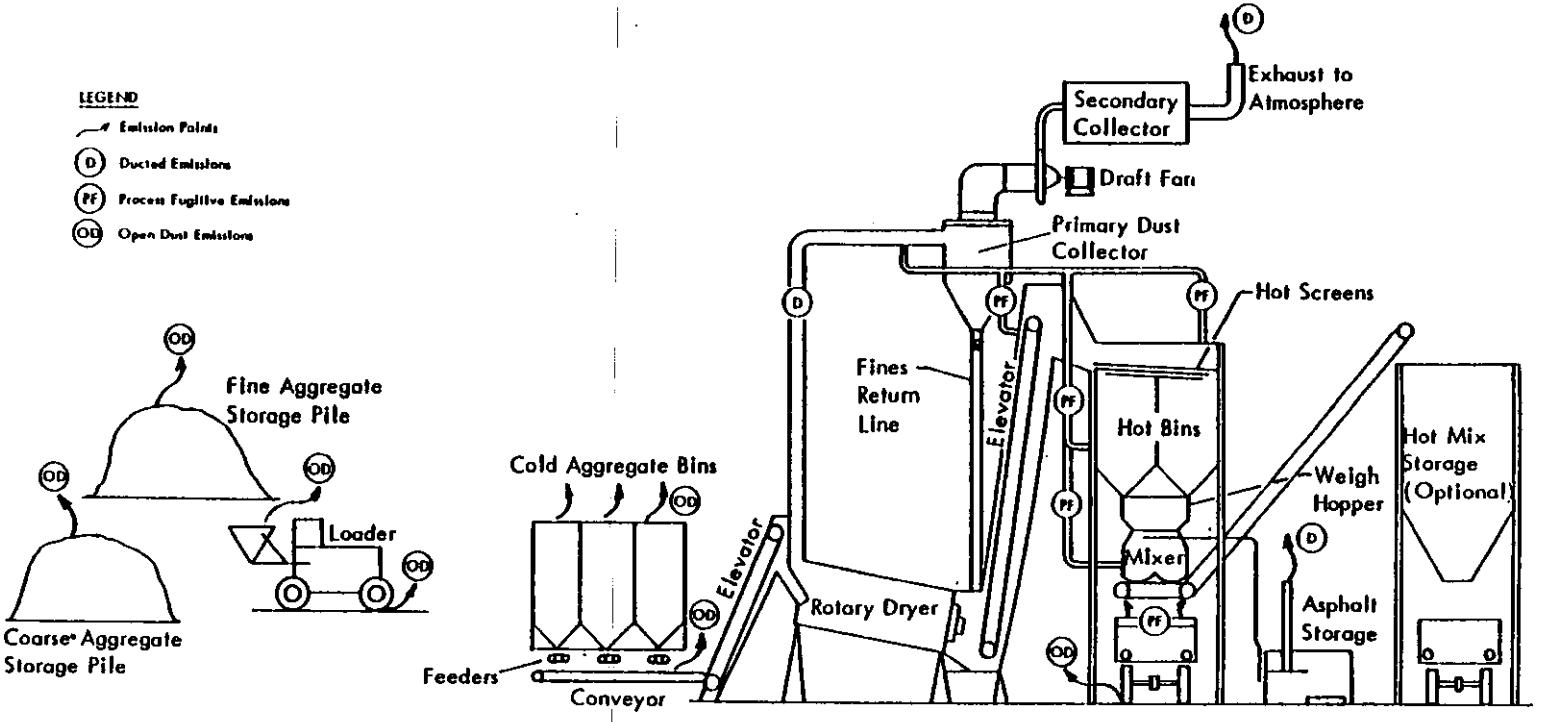

Figure 2-1. General process flow diagram for batch-mix asphalt paving plants.[6]

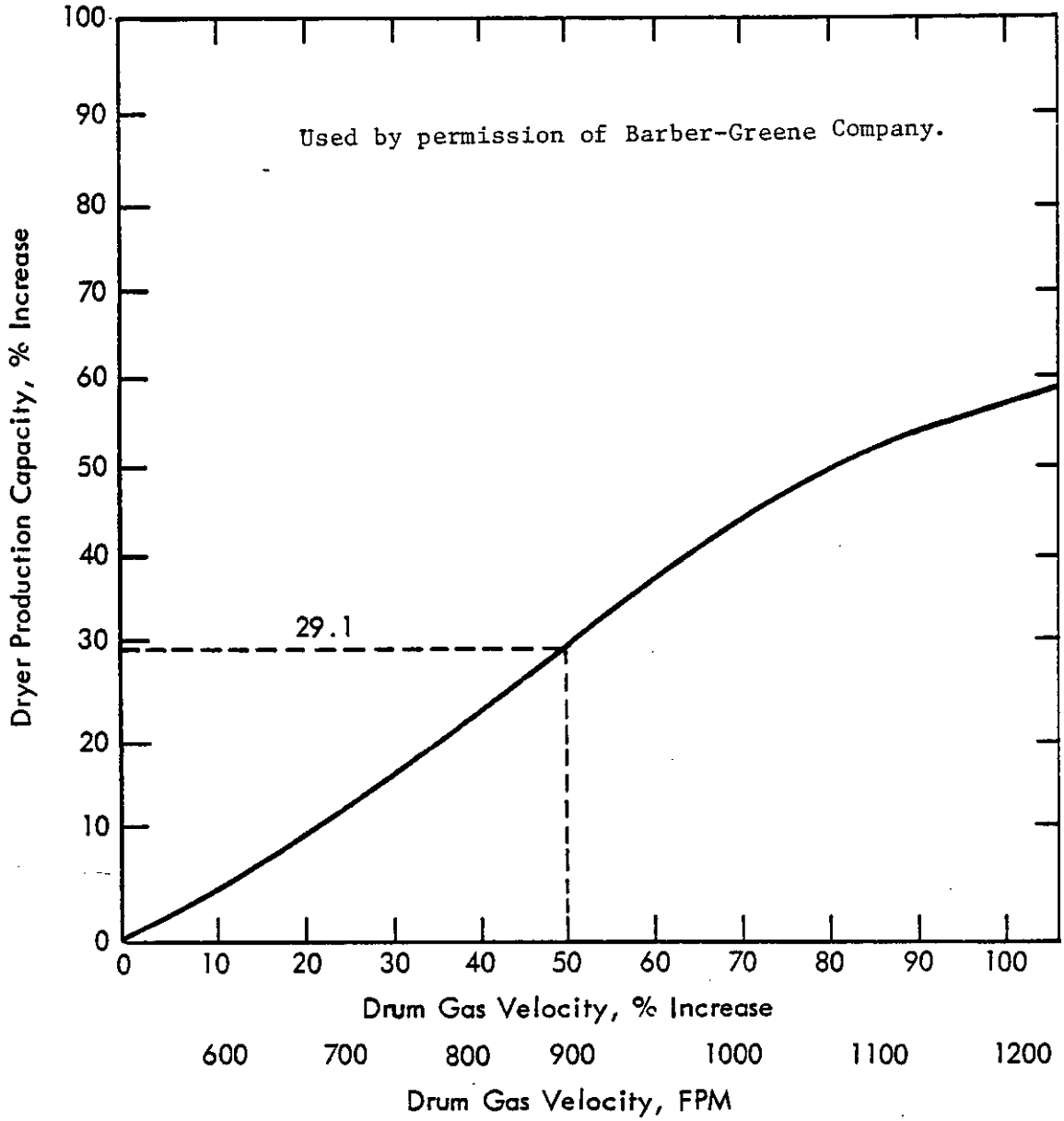

Figure 2-2. Effect of drum gas velocity on the production capacity for rotary dryers.[7]

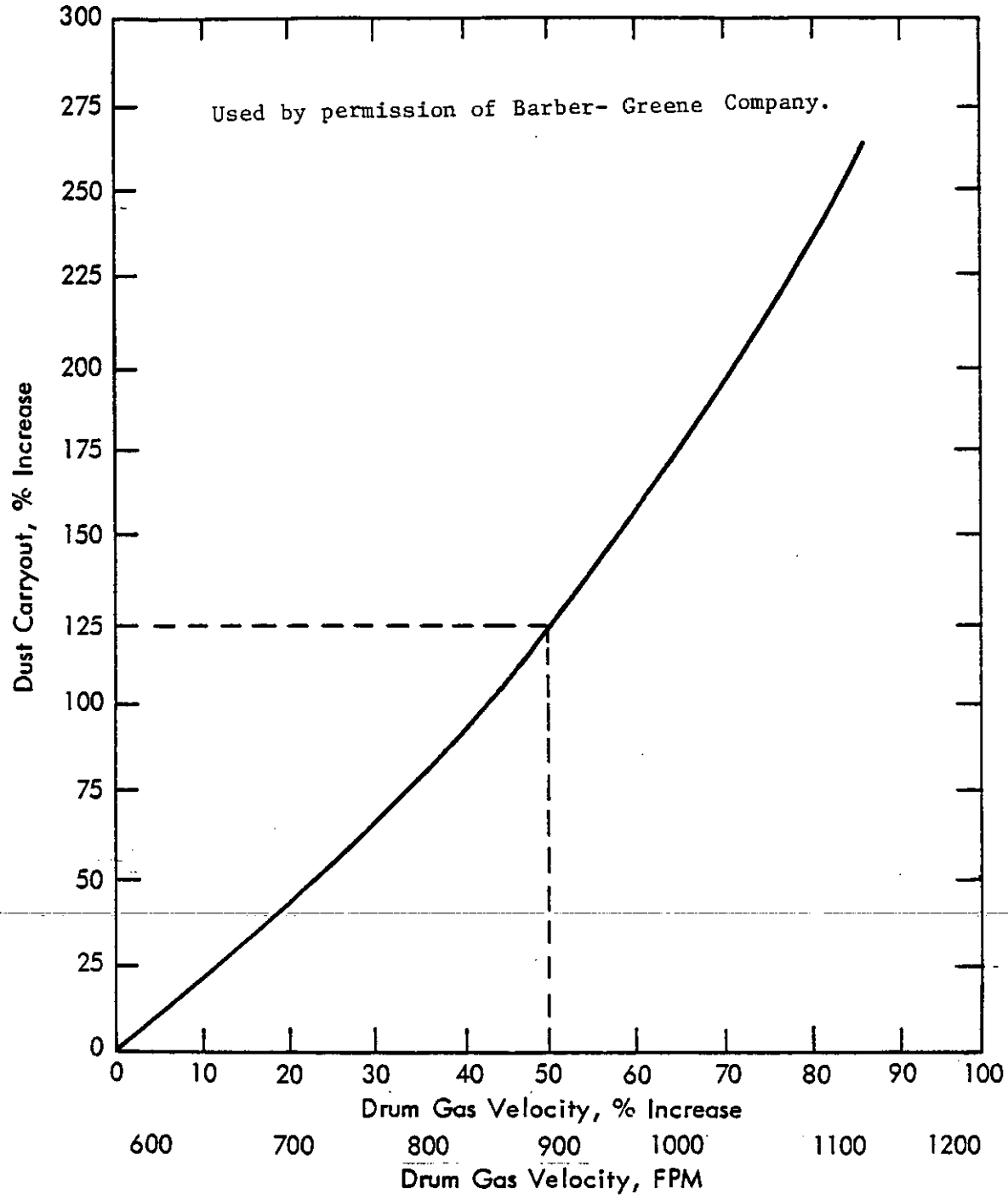

Figure 2-3. Effect of drum gas velocity on dust carryout for rotary dryers.[7]

In general, if the Stoke's settling velocity of an aggregate particle is of the same order of magnitude as the gas velocity through the dryer, the particle will probably be entrained in the gas stream and swept out of the dryer.[6]

The major source of process fugitives in asphalt batch plants comes from enclosures over the hot-side conveying, classifying, and mixing equipment which are vented into the primary collection equipment along with the dryer gas. These vents and enclosures are commonly called the "fugitive air" or "scavenger" system. The scavenger system may or may not have its own separate air mover depending on the particular facility.

The particulate emissions captured and transported by the scavenger system consist mostly of aggregate dust but may also contain a fine aerosol of condensed liquid particles. This liquid aerosol is created by condensation of the organic vapors volatilized from the asphalt cement in the pugmill.[8] The amount of liquid aerosol produced depends to a large extent on the temperature of the asphaltic cement and aggregate entering the pugmill.

There are also a number of open dust sources associated with asphalt batch plants. These include the fugitive dust generated by vehicular traffic on paved and unpaved roads, the dust created by the storage and handling of the aggregate material, and similar operations. The number and type of fugitive emission sources which are associated with a particular plant depend on whether the equipment is portable or stationary, whether it is located adjacent to a gravel pit or quarry, and the inherent aggregate moisture.

To illustrate the various sources of particulate emissions associated with asphalt batch plants, the type and location of each emission point throughout the process flow are shown in Figure 2-1.

2.2.2 Continuous-Mix Process

The continuous-mix process is generally similar to that of batch plants with the exception that slight modifications have been made to the hot-side conveying equipment. In a continuous plant, the classified aggregate drops from the vibrating screens into a set of small bins. The purpose of these bins is to collect and meter the classified aggregate to the mixer; thus, they do not provide a large amount of surge capacity. From the hot bins, the aggregate is metered through feeder conveyors to a second bucket elevator and into the mixer. Hot asphalt is metered into the inlet end of the mixer, and the mix is conveyed through the unit by the action of the rotating paddles. Retention time is controlled (and some surge capacity provided) by an adjustable dam at the end of the mixer trough. The asphalt concrete flows out of the mixer into a surge hopper for loading into trucks.

In some plants, surge capacity is provided by a set of separate hot mix storage bins. These bins, which may be either heated or nonheated, are often sealed from contact with the ambient air to prevent oxidation. If storage bins are used, the mix is conveyed from the mixer to the storage bins and trucks are loaded from the bins. A flow diagram of the continuous-mix process is shown in Figure 2-4.

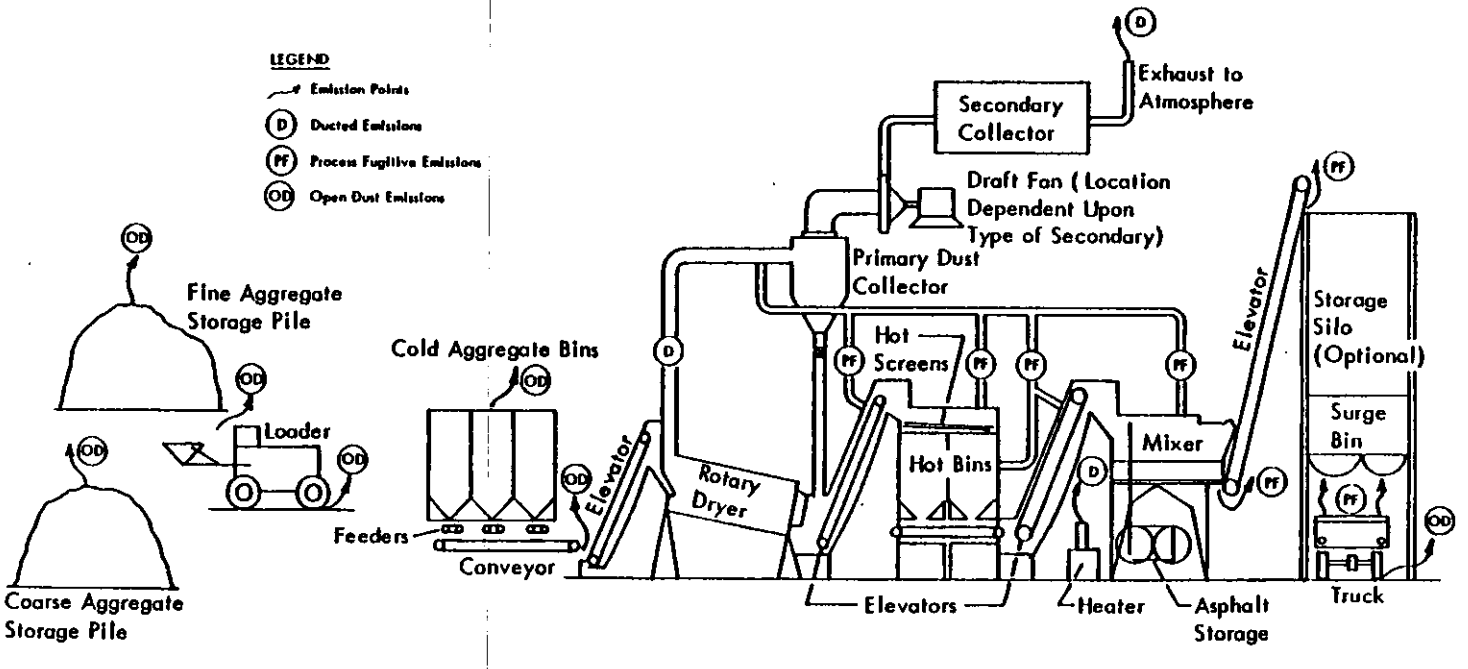

Figure 2-4. General process flow diagram for continuous-mix asphalt paving plants.

The particulate emissions from continuous-mix asphalt plants are generated in the same manner as for batch plants, except that an additional hot-side conveyor is used which would tend to increase the amount of dust collected by the scavenger system. Otherwise, there are no substantial differences in the mechanisms which produce the emissions. The various sources of particulate emissions associated with continuous-mix asphalt plants are identified in Figure 2-4.[6]

2.2.3 Drum-Mix Process

The third type of process utilized for the production of asphalt paving mixtures is the drum-mix process. This process is relatively new to the industry and is becoming increasingly more popular due to its lower capital and operating costs and its simplified production process. The most significant difference between the drum-mix process and the others described above is that the aggregate is dried, mixed, and combined with the asphalt cement inside a single unit (rotary drum mixer) thus eliminating a substantial amount of mechanical equipment.[9]

During normal operation, proportioned aggregate from the cold feed bins is transported by belt conveyor to either a vibrating screen where the larger material is rejected or directly to the drum mixer. The already combined aggregate is then introduced into the uphill end of the rotating drum mixer where it passes through the hot gases and is heated to a temperature of 300°F to remove moisture. The aggregate is tumbled by the flights as it travels the length of the drum in parallel flow with the combustion gases from the burner. This is opposite to the batch process where a counterflow arrangement is used. Asphalt cement from a heated storage tank is introduced from the opposite end of the drum where it is mixed with the heated aggregate to produce hot mix asphalt paving. The point at which the asphalt cement is injected varies from plant to plant but is generally more than halfway down the length of the drum. The asphalt is protected from coming into direct contact with the burner flame not only by distance but also by the dense curtain of falling aggregate. In a few cases, a metal barrier (flame shield) is installed in the drum to provide additional protection for the asphalt cement. The hot mix (120 to 140°C)[10] is discharged from the drum mixer and transported by inclined belt conveyor to storage silos for eventual loading into trucks and transport to the job site. A diagram of the drum-mix process is shown in Figure 2-5.

Inside the drum mixer four basic processes occur. These are bulk moisture removal; asphalt injection with partial coating; foaming (which completes the coating process); and rapid temperature rise of the mix.[10,11] Upon entering the dryer, the aggregate is directly exposed to radiant heat which vaporizes most of the moisture in the aggregate. As the aggregate continues down the length of the drum, out of contact with the flame, it reaches the asphalt injection point. At this point, the liquid asphalt is injected by a shielded pipe. In some plants, chemical additives (e.g., liquid silicon added at the refinery or by the distributor) are injected along with the asphalt to improve the distribution of the spray and its adhesion to the aggregate surface.[9,10] After asphalt injection, the aggregate attains a temperature high enough to vaporize the remaining moisture

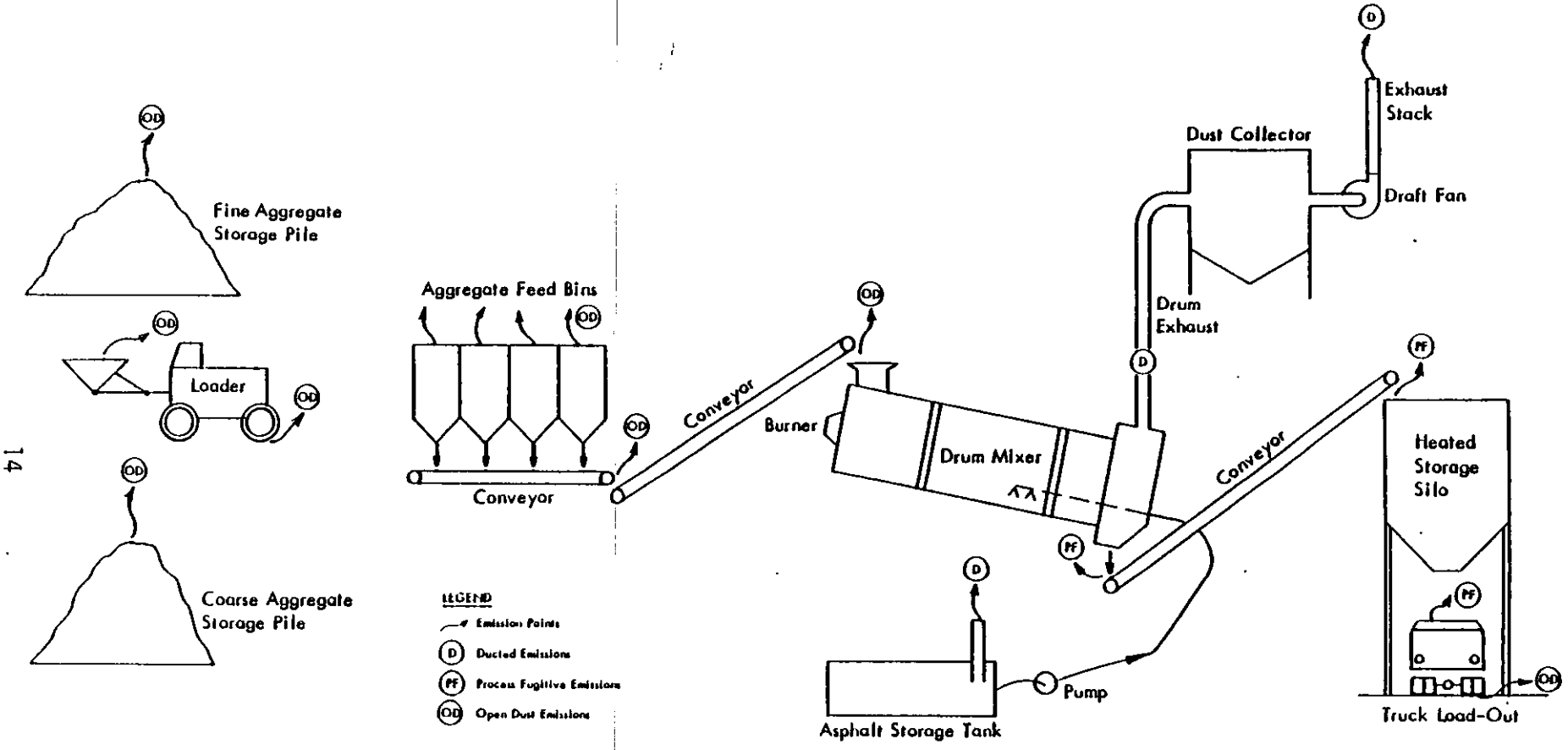

Figure 2-5. General process flow diagram for drum-mix asphalt paving plants.

in the pores of the rock. As this water vapor reaches the surface, it escapes by foaming through the asphalt coating, which is thought to increase its uniformity of film thickness. Near the discharge end of the drum, sufficient heat is absorbed in the aggregate itself to increase the mix temperature, since the bulk of the moisture has already been vaporized. The total residence time ranges from 3 to 5 min.[10,11]

As with the other two processes used for the production of asphalt concrete, the major ducted source of particulate emissions is the drum mixer itself, but emissions are significantly lower than in batch and continuous plants. This overall reduction in emissions is due to the coating of the finer particles with the asphalt cement. The emissions from the drum mixer consist of a gas stream containing a substantial amount of particulate matter and lesser amounts of gaseous organic compounds of various species.[9] The particulate generally consists of fine aggregate particles entrained in the flowing gas stream during the drying process. The organic compounds, on the other hand, are a result of the heating and mixing of the asphalt cement inside the drum, which volatilizes certain components of the asphalt. Once the volatile organic compounds have sufficiently cooled, they condense to form a fine liquid aerosol or "blue smoke," the quantity of which depends on the type of asphalt cement and temperature.[9,10] Filaments of asphalt cement can also be produced through a similar process.

A number of measures have been introduced in the newer plants to reduce or eliminate blue smoke, including the installation of flame shields, rearrangement of the flights inside the drum, adjustments in the asphalt injection point, and other design changes.[9,10] These modifications have resulted in significant improvements in the elimination of blue smoke.

The process fugitive emissions from the hot-side screens, bins, elevators, and pugmill normally associated with batch and continuous-mix plants have been eliminated in the drum-mix process. There may be, however, a certain amount of fugitive liquid aerosol produced during the transport and handling of the hot mix from the drum mixer to the storage silo if an open conveyor is used. Otherwise, the remaining open dust sources are similar to those found in batch or continuous plants. The location of each emission point throughout the drum-mix process is shown on Figure 2-5.

2.2.4 Recycle Processes

In recent years, a new practice has been initiated in the asphalt concrete industry. This practice involves the recycling of old asphalt paving. Recycling significantly reduces the amount of new (virgin) rock and asphalt cement needed to repave an existing road base. The various recycling techniques include both cold and hot methods. Since this report addresses only hot-mix asphalt processes, discussion will be limited to recycling at a central plant.

For recycling, old asphalt pavement is broken up at the job site and removed from the road base. This material is then transported to the plant, crushed, and screened to the appropriate size for further processing. It

is then heated and mixed with superheated new or virgin aggregate (if applicable) to which the proper amount of new asphalt cement is added to produce an adequate grade of hot asphalt paving suitable for laying.

There are basically three methods which can be used for heating of recycled asphalt paving (RAP) prior to the addition of the asphalt cement.[10,12] These methods are direct flame heating, indirect flame heating, and superheated aggregate. Each is discussed in the following subsections.

2.2.4.1 Direct Flame Heating--

Direct flame heating is typically performed with a drum mixer wherein all materials are simultaneously mixed in the revolving drum. The first experimental attempts at recycling used a standard drum-mix plant and introduced the recycled paving and virgin aggregate concurrently at the burner end of the drum. Numerous problems with excessive blue smoke emissions led to several modifications to the process, including the addition of heat shields and the use of split feeds.[12]

Heat dispersion is a method used for recycling. A heat shield is installed around the burner and additional cooling air is provided to reduce the hot gases to a temperature below about 430 to 650°C (800 to 1200°F), thus decreasing the amount of blue smoke.[12] However, the heat shield also accounts for a higher gas velocity and turbulence due to the restriction in the free flow of the burner gas.[13] This type of equipment can successfully recycle a mixture of up to approximately 70% recycled asphalt concrete.[12]

The concept of a drum within a drum has also been successfully utilized for recycling. This process is based on a small diameter drum being inserted into a conventional drum-mix unit. Virgin aggregate is introduced into the inner drum where it is superheated to approximately 150 to 260°C (300 to 500°F).[12] Reclaimed material is introduced into the outer drum through a second charging chute. The reclaimed material and the heated virgin aggregate meet at the discharge point of the inner drum where heat transfer occurs. This type of equipment can successfully recycle mixtures containing up to about 50 to 60% recycled bituminous materials.[12]

Split feed drum mixers were first utilized for recycling in 1976 and are now the process used most often. New aggregate is introduced at the flame end of the drum where it is superheated to 150 to 260°C (300 to 500°F).[12] At about the midpoint of the drum the recycled bituminous material is introduced by a split feed arrangement and heated by the hot gases as well as by heat transfer from the superheated virgin aggregate. This type of equipment can successfully recycle mixtures containing up to about 60 to 70% recycled bituminous material.[12]

The last type of direct flame method involves the use of a slinger conveyor to throw recycled asphalt into the center of the drum mixer from the discharge end. This arrangement is sold as a kit for the retrofit of existing plants. In this process, the RAP material enters the drum along an arc landing in the appropriate area of the asphalt injection point. A slinger conveyor should be capable of recycling mixtures containing about the same amount of RAP (i.e., 50 to 70%) as the other direct flame methods mentioned above.[12]

2.2.4.2 *Indirect Flame Heating*--

Indirect flame heating has been performed with special drum mixers equipped with heat exchanger tubes. These tubes prevent the virgin aggregate/recycled paving mixture from coming into direct contact with the flame and the associated high temperatures. These plants are capable of processing up to 100% recycled bituminous material but account for lower production for similarly sized dryers.[12]

2.2.4.3 Superheated Aggregate--

Superheated aggregate can also be utilized to heat recycled bituminous material. As noted above, two of the direct flame methods also make use of this concept to a certain extent to partially heat the recycled material.

In standard batch or continuous mix plants recycled paving can be introduced either into the pugmill or at the discharge end of the dryer, at which point the temperature of the material is raised by heat transfer from the virgin aggregate. The proper amount of new asphalt cement is then added to the virgin aggregate/recycled paving mixture to produce high grade asphalt concrete. The percentage of recycled pavement is ususally below 30%.

Tandem drum mixers can also be utilized for heating of the recycle material. The first drum or aggregate dryer is used to superheat the virgin aggregate, and a second drum or dryer is provided either to heat only recycled paving material or to mix and heat a combination of virgin and recycled paving material.[12] It is possible to use the exhaust gas from the first dryer as a heat source for the second unit. The recycling technique utilizing superheated aggregate is limited to about 50% recycled bituminous material.

There are a number of process-related variables affecting the generation of emissions from asphalt recycling processes. These include the method of heating the RAP, the percentage of RAP versus virgin material used, and the introduction of chemical additives to the mix. The exact nature of how each variable affects the quantity of emissions produced or how recycle emissions compare with plants utilizing 100% virgin aggregate is not yet known.

2.2.5 Industry Distribution

There were approximately 4,500 asphalt concrete plants operating in the United States during 1981 which produced 264 million metric tons (290 million short tons) of hot mix paving.[13] Of the various processes described above, batch-mix plants are currently the most common. However, most of the plants being sold as either new installations or as replacements to existing equipment are of the drum-mix type. To illustrate the distribution of asphalt paving plants by type of process, Table 2-4 presents data on the percentage of plants by process, production capacity, and those equipped for recycling for calendar years 1979 and 1980.[13] Comparing the information contained in Table 2-4 with that presented in a 1977 EPA study,[2] it was determined that the percentage of drum-mix facilities has increased from 2.6% to 15% of the total plant population over a 5-year period (1975 to 1980). Due to the significant economic savings associated with the drum mix process, it is expected that the trend toward an increased usage of this type of equipment should continue in the future.

TABLE 2-4. DISTRIBUTION OF ASPHALT PAVING PLANTS BY TYPE OF PROCESS[a]

Type of process	Percentage of asphalt plants by production capacity								Percentage of plants equipped for recycling	
	< 150 tons/hr[b]		150-300 tons/hr		300-400 tons/hr		> 400 tons/hr			
	1979	1980	1970	1980	1979	1980	1979	1980	1979	1980
Batch mix	21%	20%	50%	49%	8%	8%	1%	1%	2%	4%
Drum mix	2%	2%	7%	8%	3%	4%	1%	1%	2%	4%
Continuous mix	3%	3%	2%	2%	1%	1%	1%	1%	-	-

[a] Per reference No. 13. No data available on the number of uncontrolled facilities.

[b] No data available for plants < 150 ton/hr production capacity.

2.3 CONTROL TECHNOLOGY

2.3.1 Ducted and Process Fugitive Emissions

Particulate matter from the dryer (or drum mixer) and the scavenger system is removed from the gas stream prior to being discharged into the atmosphere by one or more air pollution control devices. In the case of batch and continuous mix plants, two dust collectors are usually arranged in series. The primary collector is a low efficiency device which essentially removes the larger particles, with a secondary collector being employed to complete final cleanup of the stack gas to the required degree (Figures 2-1, 2-4, and 2-5).

Almost every plant has at least a primary dust collector which was originally used to prevent dust nuisance, protect the air handling equipment downstream from the dryer, and for product recovery. Such equipment proved to be economically attractive as the aggregate it recovered could be recycled. Generally, the primary collector cannot meet current particulate emission regulations but does considerably reduce the load on the secondary collector.

Secondary collectors are used to achieve final control of emissions to the atmosphere in batch and continuous plants. These collectors are more efficient than primary collectors and are able to remove particles in the smaller size ranges. Material recovered from the secondary collector may be recycled (baghouse) or discarded (scrubber) depending on economic feasibility. Secondary collectors may be further subdivided into wet and dry types.

It is currently standard practice in drum-mix plants to utilize only one high efficiency collector for gas cleaning purposes though primary collectors are on the rise (Figure 2-5). In those cases where a baghouse is used and the aggregate contains only a small percentage of < 200 mesh (74 μm) material, primary collectors are of little use since the rate at which the dust cake builds up on the filter bags is not sufficient to enhance particle collection between cleaning cycles. In addition, drum-mix plants generally have a lower overall mass loading which allows a smaller capacity control system to be used.[9,10,11]

Particulate control technology for asphalt concrete plants can be classified into the following categories: gravity settling or expansion chambers (knock-out boxes); centrifugal collectors (cyclones); wet scrubbers; and fabric filters (baghouses).

For batch and continuous mix plants, settling chambers and cyclones (single or multiple) are typically employed as primary collectors, and wet scrubbers and baghouses are used for secondary control. The types of wet scrubbers utilized in such facilities include gravity spray towers, wet fans, and centrifugal (cyclonic), orifice plate, and venturi scrubbers. For drum-mix plants, venturi scrubbers and baghouses are the predominant control technology. A number of good references are available which describe the theory and operation of the control devices listed above.[2,14-16]

The type of device or combination of devices installed on a particular plant depends on the process and whether it is classified as a new facility required to meet applicable New Source Performance Standards (0.04 gr/dscf) or whether only state and local regulations apply. Table 2-5 presents the overall distribution of primary and secondary control devices used in the asphalt concrete industry as published in a 1977 EPA report.[2] From this table it was determined that a dry centrifugal collector (cyclone) followed by a baghouse (fabric filter) is the most common type of air pollution system utilized at the time which the subject report was published. Such a distribution may or may not be the case at present, since the percentage of drum-mix facilities which have generally no primary collector, has increased significantly since 1975.[2,13]

TABLE 2-5. PRIMARY AND SECONDARY CONTROL DEVICES USED IN THE ASPHALT CONCRETE INDUSTRY[2]

Type of control equipment	Percent of industry[a]
Primary collectors	
Settling or expansion chambers	4
Single cyclone dust collectors	58
Multiple cyclone dust collectors	35
Other	3
Secondary collectors	
Gravity spray tower	8
Cyclone scrubber	24
Venturi scrubber	16
Orifice scrubber	8
Baghouse (fabric filter)	40
Other	3

[a] An accelerating trend from gravity spray towers and cyclone scrubbers towards venturi scrubbers and baghouses has been observed since 1975. A survey conducted in 1983 of a limited number of plants showed that wet collectors were used in 52.2% of the facilities and fabric filters in 47.8% of the plant population surveyed. A heavy bias towards scrubbers was observed in the Central and Southern regions of the country.

2.3.2 Open Dust Sources

As stated previously, there are a number of open dust sources associated with asphalt concrete plants, including vehicular traffic on paved and unpaved roads, conveyor transfer points, aggregate storage piles, and batch load-in operations. There are many alternative methods which could potentially be employed to control emissions from such sources. Wet suppression is sometimes used for the control of fugitive dust from open dust sources in asphalt plants.[17] Other more sophisticated measures such as enclosed silos, conveyors, etc., and capture and collection systems are also used to control emissions from open dust sources but are generally not common in these facilities.[17]

In general, wet suppression involves the application of water or a water solution with a chemical additive (surfactant, foaming agent, or chemical binder) to the dust-producing surface to prevent the finer particles from becoming airborne as a result of some type of mechanical disturbance. Although it is the exception rather than the rule, water may be applied to unpaved roads in the plant area by a tanker truck. In arid areas such as the southwestern United States where the mineral aggregate moisture is below 2%, spray nozzles are sometimes installed to wet the material before it is conveyed from one belt to another.[17] Enclosures at transfer points also may be used in conjunction with or in place of wet suppression. Watering of storage piles can be used if dust emissions from wind erosion and materials handling (i.e., load-in, load-out) become a problem.

In actual practice, the use of water during the transfer and handling of the aggregate material is generally avoided wherever possible because whatever additional moisture that is added to the material prior to processing must eventually be removed by the dryer in order to meet mix specifications. An overall control strategy for a facility generally consists of at least watering of unpaved roads, with additional measures being employed on a case-by-case basis. The specific controls used at a particular plant depends on individual requirements imposed by the applicable regulatory agency.

REFERENCES FOR SECTION 2

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12. Interim Guidelines for Recycling Pavement Materials, Texas A&M University, College Station, TX, July 1978.

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17. Written communication from Fred Kloiber, Fred Kloiber Associates, College Park, MD, to John Kinsey, Midwest Research Institute, Kansas City, MO, January 16, 1984.

3.0 DATA REVIEW AND EMISSION FACTOR DEVELOPMENT

3.1 LITERATURE SEARCH AND SCREENING

The first step of this investigation was an extensive search of the available literature relating to the particulate emissions associated with asphalt concrete plants. This search included data collected under the current inhalable particulate characterization program, information contained in the computerized Fine Particle Emission Inventory System (FPEIS), background documents for Section 8.1 of AP-42 located in the files of the EPA's Office of Air Quality Planning and Standards (OAQPS), and other reliable sources including MRI's own library. The search was thorough but not exhaustive. It is expected that certain additional information may also exist, but limitations in funding precluded further searching.

Some 27 reference documents were collected and reviewed.[1-27] At the end of this section, each document is listed in chronological order with an indication as to whether the document contains particle size data.

To reduce the large amount of literature collected to a final group of references pertinent to this report, the following general criteria were used:

1. The information contained in the report must characterize the emissions by particle size. Documents were eliminated from consideration if only total mass emissions were determined. (This included most of the original data base utilized to derive the existing emission factors in Table 8.1-3 and Table 8.1-5 of AP-42.)

2. Source testing must be a part of the referenced study. Some reports reiterate information from previous studies and thus were not considered.

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

A final set of reference materials was compiled after a thorough review of the pertinent reports, documents, and information according to the three criteria stated above. This set of documents was further analyzed to derive candidate emission factors according to particle size.

3.2 EMISSION DATA QUALITY RATING SYSTEM

As part of MRI's analysis of the available data, the final set of eight reference documents (References 1, 3, 8, 10, 12, 23, 26, and 27) were evaluated as to the quantity and quality of the information contained in them. The following data were always excluded from consideration.[28]

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

2. Test series representing incompatible test methods.

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

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

5. Test series in which it is not clear whether the emissions measured were controlled or uncontrolled.

If there was no reason to exclude a particular data set, each was assigned a rating as to its quality. The rating system used was that specified by the OAQPS for the preparation of AP-42 Sections.[28] The data were rated as follows:

A - Multiple tests performed on the same source using sound methodology and reported in enough detail for adequate validation. These tests do not necessarily have to conform to the methodology specified in the IP protocol documents, although such methods were certainly used as a guide.

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

C - Tests that are based on an untested or new methodology or that lack a significant amount of background data.

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

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

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

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

3. Sampling and process data. Adequate sampling and process data are documented in the report. Many variations can occur without warning during testing and sometimes without being noticed. Such variations can induce wide deviations in sampling results. If a large spread between test results cannot be explained by information contained in the test report, the data are suspect and were given a lower rating.

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

3.3 PARTICLE SIZE DETERMINATION

There is no one method which is universally accepted for the determination of particle size. A number of different techniques can be used which measure the size of particles according to their basic physical properties. Since there is no "standard" method(s) of particle size analysis, a certain degree of subjective evaluation was used to determine if a test series was performed using sound methodology. The following is a brief explanation of how particle size is defined and the various methods available for particle size measurement.

3.3.1 Particle Size Definitions

Examination of particles with the aid of an optical or electron microscope involves the physical measurement of a linear dimension of a particle. The measured "particle size" is related to the particle perimeter or to the particle projected area diameter. Particle size measurement in this manner does not account for variation in particle density or shape.[29]

All laws describing the properties of aerosols can be expressed most simply for particles of spherical shape. To accommodate nonspherical particles it is customary to define a "coefficient of sphericity" which is the ratio of the surface area of a sphere with the same volume as the given particle to the surface area of the particle.[29] An estimate of particle volume can be obtained from microscopic sizing, and by assuming a density, one can obtain an estimate of particle weight.

Because of large variations in particle density and the aggregated nature of atmospheric particles, it is useful to define other quantities as a measure of particle size based on their aerodynamic behavior. The Stoke's diameter is defined as the diameter of a sphere having the same settling velocity as the particle and a density equal to that of the bulk material from which the particle was formed, or[30]:

$$D_s = \sqrt{\frac{18\ V_s\ \eta}{g\ e\ C(D_s)}} \quad \text{for Re} \leq 0.5 \qquad (1)$$

where:

D_s = Stoke's diameter (cm)

V_s = terminal settling velocity of a particle in free fall (cm/sec)

η = viscosity of the fluid (gm/cm·sec)

g = gravitational constant (980.665 cm/sec^2)

e = density of the particle (gm/cm^3)

$C(D_s)$ = Cunningham's slip correction factor for spherical particles of diameter D_s (dimensionless)

$$\cong 1 + \frac{2A\lambda}{D_s} \qquad (2)$$

$$A = \alpha + \beta \exp(-\gamma\ D_s/2\lambda) \qquad (3)$$

α = empirical constant (dimensionless) $\cong$ 1.23 - 1.246
β = empirical constant (dimensionless) $\cong$ 0.41 - 0.45
γ = empirical constant (dimensionless) $\cong$ 0.88 - 1.08
λ = mean free path of the fluid at stated conditions (cm)

$$\cong \lambda_o\ (\eta/\eta_o)\ (T/T_o)^{0.5}\ (P_o/P) \qquad (4)$$

λ_o = mean free path at reference conditions (cm)
η = gas viscosity at stated conditions (gm/cm·sec)
η_o = gas viscosity at reference conditions (gm/cm·sec)
T = absolute temperature (°K)
T_o = reference temperature = 296.16°K
P = absolute pressure (kPa)
P_o = reference pressure = 101.3 kPa
Re = Reynold's number (dimensionless)

For particles greater than a few microns in diameter, a less rigorous form of Equation 1 can be used with reasonable accuracy according to the relationship:[31,32]

$$D_s = \sqrt{\frac{18\ \eta\ V_s}{(e - e')g}} \qquad Re \leq 0.05 \qquad (5)$$

where:

e, g, D_s, and η are as defined above; and

e' = density of air at the appropriate temperature and pressure (gm/cm^3)

Since dispersion and condensation aerosols are usually formed from many materials of different densities, it is more useful to define another parameter called the aerodynamic diameter, which is the diameter of a sphere having the same falling velocity as the particle and a density equal to 1 g/cm^3.[29,30] The classical aerodynamic diameter differs from the Stoke's diameter only by virtue of difference in density, assumed equal to unity, and the slip correction factor, which, by convention, is calculated for the aerodynamic equivalent diameter. From Equation 1:[30]

$$D_{Ae} = \sqrt{\frac{18\eta V_s}{gC(D_{Ae})}} \qquad (6)$$

where D_{Ae} = "classical" aerodynamic equivalent diameter (cm), with η, V_s, g, C as previously defined in Equation 1.

Equations required for interconversion between Stoke's and aerodynamic diameters are presented in Table 3-1.[30]

3.3.2 Particle Size Measurement

As stated previously above, particle size is determined by measuring certain physical properties of the particulate being analyzed, such as its inertial, light scattering, sedimentation, diffusional, and electrical characteristics. The size distribution of an aerosol can be determined either directly at the source (i.e., stack or vent) or indirectly by the collection of a bulk sample of the material for subsequent analysis in the laboratory. In either case, the instrument(s) utilized to make such a determination can be manual or automated depending on the individual technique.

The five basic methods for the direct measurement of particle size are:

1. Aerodynamic separators (cascade impactors, cyclones, elutriators, etc.)

2. Light-scattering optical particle counters

TABLE 3-1. EQUATIONS USED FOR PARTICLE SIZE CONVERSIONS[30]

Diameter definition (given)	Conversion equation[a]	
	Stoke's diameter (D_s)	Classical aerodynamic equivalent diameter (D_{Ae})
Stoke's diameter	1.0	$D_{Ae} = D_s \left[\frac{\rho C(D_s)}{C(D_{Ae})} \right]^{1/2}$
Classical aerodynamic diameter (D_{Ae})	$D_s = D_{Ae} \left[\frac{C(D_{Ae})}{\rho C(D_s)} \right]^{1/2}$	1.0

[a] Notation: D_s = Stoke's diameter (μm)
D_{Ae} = Classical aerodynamic equivalent diameter (μm)
ρ = Particle density (g/cm³)
$C(D_s)$, $C(D_{Ae})$, = Slip correction factors (dimensionless)--see Equations 2, 3, and 4.

3. Electrical mobility analyzers
4. Condensation nuclei counters
5. Diffusion batteries

All of the above are extractive methods, with the exception of certain aerodynamic separators.

Indirect methods for the determination of particle size include:

1. Sieving (wet, dry, sonic)
2. Sedimentation
3. Centrifugation (inertial separation)
4. Microscopy (optical and electron)
5. Others (acoustic, thermal, spectrothermal emission)

Table 3-2 provides a guide as to the various methods for the determination of particle size based on certain physical properties of the particulate and notes the size range in which each is generally applicable.[33]

In most respects instruments that fractionate an aerosol on the basis of the aerodynamic properties of its components probably give the best practical assessment of size. Once flow conditions have been selected for the device, the terminal settling velocities of the particles collected in each stage or part of the instrument can be determined, even though particle specific gravity and shape factor are unknown.[30] Unless the particle shapes are extremely irregular, the details of precise geometric form can be bypassed and the likelihood of the particle's capture by a dust-collecting system can still be determined. Because the correct assessment of particle size properties is essential for the development of appropriate emission factors, an assessment by aerodynamic techniques was emphasized in reviewing and rating the individual data sets for sound methodology.

Examples of aerodynamic particle sizing instruments are centrifuges, cyclones, cascade impactors, and elutriators. Each of these instruments employs the unique relationship between a particle's diameter and mobility in gas or air to collect and classify the particles by size. For pollution studies, cyclones and impactors (primarily the latter) are more useful because they are rugged and compact enough for in situ sampling. In situ sampling is preferred because the measured size distribution may be distorted if a probe is used for sample extraction. In the following two subsections, methods of using impactors and cyclones are discussed.

3.3.2.1 Cascade Impactors--

Cascade impactors used for the determination of particle size in process streams consist of a series of plates or stages containing either small holes or slits with the size of the openings decreasing from one plate to the next. In each stage of an impactor, the gas stream passes through the orifice or slit to form a jet that is directed toward an impaction plate. For each stage there is a characteristic particle diameter that has a 50% probability of impaction. This characteristic diameter is called the cut-point (D_{50}) of the stage. Typically, commercial instruments have six to eight impaction stages with a back-up filter to collect those particles which are either too small to be collected by the last stage or which are reentrained off the various impaction surfaces by the moving gas stream.[34]

The particle collection efficiency of a particular impactor jet-plate combination is determined by properties of the aerosol such as the particle shape and density, but the viscosity of the gas, and by the design of the impactor stage. There is also a slight dependence on the type of collection surface used (glass fiber, grease, metal, etc.). Reentrainment, or particle bounce, is a significant problem with cascade impactors especially in the case of high particulate loadings. This problem can be partially solved by using a preseparation device ahead of the impactor to reduce the overall loading of coarse particles.

TABLE 3-2. GUIDE TO PARTICLE SIZE MEASUREMENT[33]

Method	Diameter of applicability (μm)
Optical	
Light imaging	0.5+
Electron imaging	0.001-15
Light scanning	1+
Electron scanning	0.1+
Direct photography	5+
Laser holography	3+
Sieving	2+
Light scattering	
Right angle	0.5+
Forward	0.3-10
Polarization	0.3-3
With condensation	0.01-0.1
Laser scan	5+
Electrical	
Current alteration	0.5+
Ion counting, unit charge	0.01-0.1
Ion counting, corona charging	0.015-1.2
Impaction	0.5+
Centrifugation	0.1+
Diffusion battery	0.001-0.5
Acoustical	
Orifice passage	15+
Sinusoidal vibration	1+
Thermal	0.1-1
Spectrothermal emission	0.1+

3.3.2.2 Cyclone Separators--

Traditionally, cyclones have been used as a preseparator ahead of a cascade impactor to remove the larger particles. These cyclones are of the standard reverse-flow design whereby the aerosol sample enters the cyclone through a tangential inlet and forms a vortex flow pattern. Particles move outward toward the cyclone wall with a velocity that is determined by the geometry and flow rate in the cyclone and by their size. Large particles reach the wall and are collected.

A series of cyclones with progressively decreasing cut-points can be used also instead of impactors to obtain particle size distributions. The advantages are that larger samples are acquired, particle bounce is not a problem, and no substrates are required. Also, longer sampling times are possible with cyclones, which can be an advantage at very dusty streams, but a disadvantage at relatively clean streams. One such series cyclone system was developed by an EPA contractor specifically for the IP program.[35]

3.4 REVIEW OF SPECIFIC DATA SETS

The following is a discussion of the data contained in each of eight primary reference documents. The documents are presented according to the Reference number indicated at the end of this section and their date of publication.

3.4.1 Reference 1 (1960)

Reference 1 is a technical paper published in the Journal of the Air Pollution Control Association, which presents the results of 25 tests conducted by personnel of the Los Angeles County Air Pollution Control District beginning in 1949. Included in this document are emissions data for batch and continuous mix asphalt plants controlled by either a multiple centrifugal scrubber or a baffled spray tower. In five of these tests, a particle size distribution was obtained at both the inlet and outlet of the scrubber. The information contained in Reference 1 was later republished in the first (1967) edition of the Air Pollution Engineering Manual (EPA document AP-40). The data were again included in a second edition of the same document in 1973. A summary of the five tests which contain particle size data is shown in Table 3-3, and a copy of the paper itself is contained in Appendix A.

There were a number of deficiencies noted in the data contained in Reference 1. The main problem was that a test method was not specified for either total mass emissions or particle size. In addition, data were not available on the operation of the process, the raw material used, or the exact configuration of the plants tested. As far as could be determined, only one set of samples was collected during each test included in Reference 1.

The data published by Los Angeles County have been cited repeatedly in numerous reports on the emissions from asphalt concrete plants. An attempt was therefore made to supplement the information contained in Reference 1 by both written and verbal communication with personnel of the South Coast Air Quality Management District (SCAQMD) (formerly the Los Angeles County

TABLE 3-3. SUMMARY OF PARTICLE DATA - REFERENCE 1[a]

Data Rating: D

Test series No.	Inlet dust loading[b] (lb/hr)	Outlet dust loading[b] (lb/hr)	Type of scrubber[c]	Production rate (tons/hr)[d]	Inlet particle size (% weight)[e]				Outlet particle size (% weight)[e]			
					0-10 µm	10-20 µm	20-44 µm	> 44 µm	0-10 µm	10-20 µm	20-44 µm	> 44 µm
C-393	4,260	26.9	T	92.3	13.0	71.1	9.6	6.3	99.3	0	0	0.7
C-369	352	24.4	C	113.0	76.4	6.3	2.8	14.5	79.9	3.8	2.0	14.3[f]
C-372A	76	10.0	C	158.0	78.0	18.0	2.0	2.0	83.0	5.0	1.0	11.0[f]
C-372B	121	19.2	C	142.9	91.0	9.0	0	0	82.0	3.0	2.0	13.0[f]
C-422(1)	-	26.6	C	198.0	80.4[g]	18.6[g]	1.0[g]	0[g]	73.2	5.1	4.5	17.2

[a] From: Tables I and II, p. 31 of Ingel, et al., "Control of Asphaltic Concrete Plants in Los Angeles County," J. Air Pollut. Control Assoc., 10(1):29-33, Feb. 1960 (Appendix A).

[b] 1 lb/hr = 0.454 kg/hr.

[c] C = multiple centrifugal spray scrubber; T = baffled spray tower.

[d] Assumed to be short tons (2,000 lb) per hour of asphalt paving produced. 1 short ton/hr = 0.907 metric tons/hr = 0.907 $(10)^6$ gm/hr.

[e] Stoke's diameter.

[f] Microscopic examination indicated agglomerated particles.

[g] Data not used for emission factor development.

Air Pollution Control District) to obtain copies of the original reports for the subject tests.[36] Only in two cases (Nos. C-393 and C-426) was this effort successful.[37,38] Upon reviewing the two reports supplied by the SCAQMD, it was concluded that there was still insufficient information contained in the documents from which to ascertain the exact equipment and procedure used to determine the total mass emissions from each plant and the particle size distribution. Tables 3-4 and 3-5 summarize the data obtained from Tests C-393 and C-426, respectively, with copies of the original test reports included in Appendix A.

To fill in the gaps in the available information, a telephone conversation was held with Mr. William Krenz, Manager of Source Testing and Monitoring for the SCAQMD.[39] It was learned from Mr. Krenz that the sampling apparatus used by Los Angeles County during that time period to measure the total mass emissions from a process was similar to the standard EPA Method 5 sampling train with the exception that the filter was installed downstream of the wet impingers. According to his best recollection, the particle size distribution was obtained by introducing a sample of dried particulate matter caught in the impingers of the sampling train into a commercially available instrument called a "Micromerograph." The Micromerograph consists of a sample feeder and deagglomerator installed atop a gravity sedimentation column at the bottom of which is an electronic torsion balance. This instrument measures the size distribution of the sample according to the Stoke's settling velocity of the particles. Both the sampling train and the Micromerograph are described in a source test manual published by the Los Angeles County Air Pollution Control District (APCD).[40] A technical paper describing the Micromerograph and its operation has also been included in Appendix A.[41]

The information obtained from Reference 1 and that subsequently obtained from the SCAQMD is somewhat sketchy. It would also be expected that the method used to determine the particle size distribution may not provide data that are entirely representative of the actual emissions from the process since the finer particle fraction would be collected on the filter and not in the impinger train. The size distribution could also be affected by agglomeration of the particles during preparation of the sample prior to analysis. Based on these factors and taking into consideration the time period during which the data were collected, a data quality rating of D was assigned to the information contained in Reference 1.

3.4.2 Reference 3 (1967)

Reference 3 is a technical paper published in the English version of Staub-Reinhalt, Luft outlining the results of a major research program conducted in West Germany of the emissions from asphalt concrete plants. Some 35 individual tests were conducted at 10 different facilities during the sampling program. These data were then compared against 83 additional tests at 27 other facilities as performed by other investigators. During the program, measurements were made of the total dust loading in the dryer exhaust as well as at the discharge of the primary and secondary dust collectors. In every case but one, the control system generally consisted of multiple, large diameter cyclones arranged in parallel followed by a single, low

TABLE 3-4. SUMMARY OF PARTICLE SIZE DATA FOR TEST NO. C-393[37]

Data Rating: D

Particle size range (μmS)[a]	Percent by weight[b]	
	Inlet to scrubber[c]	Outlet from scrubber[d]
0-10	13.0	99.3
10-20	71.1	-
20-44	9.6	-
> 44	6.3	0.7

[a] Stoke's diameter.

[b] Data taken from page 5 of Reference 1 (Appendix A).

[c] Baffle plate scrubber. Inlet to scrubber = outlet from a single large diameter cyclone collector.

[d] Outlet data not used for emission factor development.

TABLE 3-5. SUMMARY OF PARTICLE SIZE DATA FOR TEST NO. C-426[38]

Data Rating: D

Particle size (μmS)[a]	Cumulative percent by weight less than stated size[b]		
	Inlet to cyclone	Outlet from cyclone[c]	Vent line[d]
1,651	100	100	100
295	98.0	98.5	98.9
147	83.0	81.0	95.7
74	57.8	54.0	89.2
60	56.6	51.1	88.0
50	53.5	44.6	85.8
40	47.7	33.8	81.6
30	40.8	25.4	74.0
20	32.1	17.8	60.7
15	27.8	14.3	52.7
10	21.1	10.3	39.7
5	10.1	5.4	19.3
4	7.2[e]	4.4[e]	14.3[e]
3	4.3[e]	3.0[e]	8.5[e]
2	1.5	1.3	3.0
1	0	0	0

[a] Stoke's diameter. Fraction of material > 200 mesh (74 μm) determined by sieve analysis was also assumed to be Stoke's diameter.

[b] Data taken from page 9 of Reference 1 (Appendix A). Data for particles > 60 μmS not input to SPLIN2 program (see Section 3.5.2).

[c] Inlet to multiple centrifugal scrubber. Includes combined effluent from cyclone and vent line.

[d] Scavenger control system vent line. Includes hot side elevator, screens, bins, and weigh hopper.

[e] Data not input to SPLIN2 program (see Section 3.5.2).

energy wet scrubber. The particle size distribution was determined on the uncontrolled emissions from the dryer and at the exit of the primary collector. Exactly how such samples were obtained is not specified in the document. A copy of Reference 3 is provided in Appendix B.

As far as can be determined, the particle size data included in Reference 3 was obtained by taking a dry sample of the dust caught in the sample train and analyzing it utilizing a Gonell air elutriator according to VDI Directive 2031, "Fineness Determination of Technical Dusts." The Gonell elutriator consists of a long brass tube with a conical base.[42] The sample is placed in the inlet cone with an upward stream of air blown through the column at varying velocities to achieve separation. The theory is that as the air moves vertically upward it carries with it particles whose gravitational settling velocity is less than the velocity of the carrier gas. The amount of material remaining in the instrument is weighed and the test repeated to complete the particle size analysis. A summary of the particle size distribution of the uncontrolled emissions from the plants tested is shown in Table 3-6, and Table 3-7 provides the size distribution of the dust exiting the primary collector.

Although the data contained in Reference 3 were derived from plants located in West Germany, it is felt that these data can also be considered as characteristic of U.S. facilities as well. This opinion is based on the fact that in many cases the Germans utilize plant equipment which is manufactured in the United States.[43] In addition, the type of aggregate and asphalt cement used is also reasonably similar to that which is available in this country.[43] For the above reasons, the data included in Reference 3 were included in the development of candidate emission factors for conventional asphalt plants.

The emissions data in Reference 3 are of fairly good quality even though there are significant gaps in the sampling protocol used. As with the data contained in Reference 1, the size distribution of the particulate was determined indirectly through the use of a laboratory instrument, which can cause a certain degree of bias in the test results. Due to the lack of sufficient documentation on the exact methods used to collect and analyze the samples and detailed information on the process operating parameters of the plants tested, it is difficult to ascertain the representativeness of the results obtained. For these reasons, a rating of C was assigned to the data included in Reference 3.

3.4.3 Reference 8 (1971)

Reference 8 presents the results of a study conducted by an EPA contractor, of the atmospheric emissions from batch and continuous mix asphalt concrete plants. In this study, original source tests were conducted of the total mass emissions from five individual plants using both EPA Method 5 and a sampling train developed by the Los Angeles County APCD.[40] An industrial survey was also conducted as part of the study to obtain whatever data were available from other sources on both mass emissions and particle size.

TABLE 3-6. SUMMARY OF PARTICLE SIZE DATA FOR UNCONTROLLED EMISSIONS - REFERENCE 3[a]

Data Rating: C

Dust in the drum exhaust gases	Plant ID No.	Raw material	Raw dust concentration (g/m³ STP)	Waste gases per metric ton (m³ STP/MT)[b]	Uncontrolled emission factor[c] (kg/MT)	Particle density (g/cm³)	Raw dust in the drum waste gases particle size distribution by settling velocity intervals (weight proportion in %) < 0.2 cm/sec	< 0.4 cm/sec	< 0.8 cm/sec	< 1.6 cm/sec	< 3.2 cm/sec	< 6.4 cm/sec	< 12.8 cm/sec	< 25.6 cm/sec	> 25.6 cm/sec
1. For washed raw material in manufacture of															
1.1 Fine asphaltic concrete 0/8	A4	Moraine + Rhine sand	28.6	330	9.4	2.4	10.5	16.7	23.2	28.6	34.3	39.7	46.0	57.1	42.9
	D1	Basalt + natural sand	33.4	630	21.0	2.6	7.0	13.1	18.2	22.8	26.7	28.8	32.0	38.2	61.8
	H2	Basalt + lime + natural sand	26.2	470	12.3	2.6	8.7	17.0	23.4	27.6	33.4	36.2	45.9	59.1	40.9
	I2[d]	Basalt + lime + blast furnace slag	39.1	540	21.1	2.9	10.8	14.0	17.2	25.1	34.5	38.5	47.2	64.1	35.9
1.2 Binder 0/18	I3[d]	Lime + Rhine sand	29.3	500	14.7	2.7	13.7	29.1	40.9	49.2	58.1	64.7	70.2	80.9	19.1
1.3 Base 0/35	D2	Basalt + natural sand	29.9	630	18.8	2.9	15.1	25.0	41.1	58.1	65.4	67.0	69.1	73.3	26.7
2. For half-washed raw material in the manufacture of															
2.1 Fine asphaltic concrete 0/8	C1	Basalt + moraine + Rhine sand	69.9	520	36.3	2.5	6.9	13.8	22.0	29.6	37.2	45.9	54.7	74.1	25.9
	C2		69.5	520	36.1	2.5	7.6	16.9	24.9	31.7	37.4	42.6	50.9	58.9	41.1

(continued)

TABLE 3-6. (concluded)

Dust in the drum exhaust gases	Plant ID No.	Raw material	Raw dust concentration (g/m³ STP)	Waste gases per metric ton (m³ STP/MT)[b]	Uncontrolled emission factor[c] (kg/MT)	Particle density (g/cm³)	Raw dust in the drum waste gases particle size distribution by settling velocity intervals (weight proportion in %) < 0.2 cm/sec	< 0.4 cm/sec	< 0.8 cm/sec	< 1.6 cm/sec	< 3.2 cm/sec	< 6.4 cm/sec	< 12.8 cm/sec	< 25.6 cm/sec	> 25.6 cm/sec
3. For unwashed raw material in the manufacture of															
3.1 Fine asphaltic concrete 0/8	B3	Blast furnace slag + Rhine sand	133.5	350	46.7	2.6	4.2	7.7	12.5	18.3	25.4	32.7	41.4	56.7	43.3
	D4	Basalt	116.5	640	74.6	2.8	15.9	26.8	41.5	53.8	61.5	67.6	72.0	80.6	19.4
	F3	Limestone	119.1	310	36.9	2.4	11.0	19.8	27.7	35.5	43.2	48.9	57.6	66.9	33.1
	G2	Limestone	117.0	260	30.4	2.5	8.3	20.1	37.0	50.2	59.6	66.7	72.1	82.5	17.5
	K4	Limestone	111.2	460	51.2	2.7	1.5	2.1	2.9	3.8	4.6	6.3	10.5	16.3	83.7
3.2 Binder 0/12	G1	Diabase + lime	103.2	270	27.9	2.5	5.9	16.5	29.1	35.1	43.8	53.9	66.0	81.9	18.1
3.3 Base 0/30	B1	Gravel	53.1	300	15.9	2.5	3.6	5.1	7.0	8.9	10.9	12.8	16.3	23.7	76.3
Base 0/35	F2	Rhine gravel	52.0	280	14.6	2.5	16.5	24.0	32.5	41.5	45.6	48.5	53.0	60.4	39.6

[a] Data taken from Tables 3 and 8, pgs. 12 and 20 of Reference 3 (Appendix B). Assumed to be dryer exhaust only. Minor differences in raw dust concentration noted between Tables 3 and 8 for Plant ID's B3, C2, and D4.

[b] Assumed to be metric tons (MT) of asphalt concrete produced. 1 MT ≅ 1.1 short tons ≅ 2,200 lb = 10^6 gm.

[c] Calculated from data in two previous columns. For example: $28.6 \frac{g}{m^3} \times 330 \frac{m^3}{MT} \times \frac{1\ kg}{1{,}000\ g} = 9.4\ kg/MT$

[d] Same tests as J2 and J3 shown in original reference document.

TABLE 3-7. SUMMARY OF PARTICLE SIZE DATA FOR THE DUST EXITING THE PRIMARY COLLECTOR - REFERENCE 3[a]

Data Rating: C

Dust in the drum waste gases	Plant ID No.	Raw material	Total mass conc. exiting collector (g/m^3)[b]	Total gas volumetric flow rate (10^3 m^3/hr)[b]	Production rate (MT/hr)[c]	Emission factor (kg/MT)[d]	Proportion of dust in particle size intervals (Stoke's diameter)[e] 0-10 µm	10-20 µm	20-40 µm	> 40 µm	No. of cyclone elements[f]
1. For washed raw material in the manufacture of											
1.1 Fine asphaltic concrete 0/8	A4	Moraine + Rhine sand	0.673	17.0	25	0.458	23.2	11.1	11.7	54.0	4
	D1	Basalt + natural sand	3.23	48.6	60	2.62	18.2	8.5	5.3	68.0	2
	H2	Basalt + lime + natural sand	1.70	21.2	35	1.03	23.4	10.0	12.5	54.1	18
	I2[g]	Basalt + lime + blast furnace slag	0.82	27.5	40	0.56	17.2	17.3	12.7	52.8	20
1.2 Binder 0/18	I3[g]	Lime + Rhine sand	2.12	26.4	40	1.40	40.9	17.2	12.1	29.8	20
1.3 Base 0/35	D2	Basalt + natural sand	4.90	46.2	60	3.77	41.1	24.3	3.7	30.9	2
2. For half-washed raw material in the manufacture of											
2.1 Fine asphaltic concrete 0/8	C1	Basalt + moraine + Rhine sand	2.39	44.3	60	1.77	22.0	15.2	17.5	45.3	6
	C2		2.72	45.3	60	2.05	24.9	12.5	13.5	45.3	6

(continued)

TABLE 3-7. (concluded)

Dust in the drum waste gases	Plant ID No.	Raw material	Total mass conc. exiting collector (g/m^3)[a]	Total gas volumetric flow rate (10^3 m^3/hr)[b]	Production rate (MT/hr)[c]	Emission factor (kg/MT)[d]	Proportion of dust in particle size intervals (Stoke's diameter)[e] 0-10 µm	10-20 µm	20-40 µm	> 40 µm	No. of cyclone elements[f]
3. For unwashed raw material in the manufacture of											
3.1 Fine asphaltic concrete 0/8	B3	Blast furnace slag + Rhine sand	2.27	34.5	64	1.22	12.5	12.9	16.0	58.6	21 + 12[h]
	D4	Basalt	12.9	44.5	55	10.4	41.5	20.0	10.5	28.0	2
	F3	Limestone	6.10	27.0	70	2.35	27.7	15.5	14.4	42.4	6
	G2	Limestone	10.3	26.3	90	3.08	37.0	22.6	12.5	27.9	4
	K4	Limestone	3.08	43.0	75	1.77	2.9	1.7	5.9	89.5	6
3.2 Binder 0/12	G1	Diabase + lime	8.3	30.8	80	3.20	29.1	14.7	22.2	34.0	4
3.3 Base 0/30	B1	Gravel	0.916	34.4	70	0.449	7.0	3.9	5.4	83.7	21 + 12[h]
Base 0/35	F2	Rhine gravel	3.12	25.6	70	1.14	32.5	13.1	7.4	47.0	6

[a] Multiple cyclone dust collectors. Data taken from Table 3, p. 12, and Table 9, p. 22 of the Reference 3 (Appendix B). Calculations rounded to three significant figures.

[b] At actual temperature and pressure.

[c] Assumed to be metric tons (MT) of asphalt concrete produced. 1 MT ≅ 1.1 short ton ≅ 2,200 lb = 10^6 gm.

[d] Calculated from data in three previous columns. For example: $0.673 \frac{g}{m^3} \times 17.0\ (10)^3 \frac{m^3}{hr} \times \frac{1\ hr}{25\ MT} \times \frac{1\ kg}{1{,}000\ g} = 0.458 \frac{kg}{MT}$

[e] Density assumed equal to 2.6 g/cm^3.

[f] From Table 1, p. 10 of Reference 3.

[g] Same tests as J2 and J3 shown in original reference document.

[h] Two sets of cyclones in series.

Four particle size distribution curves are presented in Reference 8 with two of these curves representing plants with centrifugal scrubbers and the remaining data representing plants with spray towers. There is no information contained in the report on either the plants tested or the methods used to determine the particle size distributions. A copy of Reference 8 is provided in Appendix C.

To augment the particle size information contained in Reference 8, the EPA contractor who performed the study was contracted to extract the original data used to prepare the four particle size distribution curves mentioned above from the project files.[44] From this effort, three separate test reports were supplied to MRI consisting of data collected by CMI Systems of Chattanooga, Tennessee. Two of these tests were determined to be suitable for the development candidate emission factors.[45,46] Summaries of these data are shown in Tables 3-8 and 3-9, respectively, with copies of the original reports provided in Appendix C.

The two CMI documents mentioned above provide the results of particle size tests conducted at two batch-mix asphalt plants controlled by a single cyclone dust collector, followed by a wet scrubber. One of these plants was equipped with a spray tower (Sloan) and the other a centrifugal scrubber (Harrison). Samples were collected both downstream of the cyclone (inlet to the scrubber) and from the exhaust stack (outlet of the scrubber) utilizing an Andersen nine-stage, in-stack cascade impactor. This equipment is not fully described in the test reports themselves but is explained in some detail in the third document received from the EPA contractor.[47] As far as could be determined, two sets of samples were collected at the Sloan plant and one set at the Harrison facility. The sampling duration for all particle size tests was 5 min.

The tests conducted by CMI Systems were generally based on accepted methodology but do lack documentation on process operation, type of raw material utilized, and certain key information with regard to the collection and analysis of the samples. In addition, the small number of test runs and their short duration would somewhat decrease the overall representativeness of the data over the entire range of process operating conditions. Due to these considerations, a rating of B was assigned to the information contained in Reference 8 and the supplementary test reports supplied by the EPA contractor.

3.4.4 Reference 10 (1972)

Reference 10 is a report of a source test conducted by Glen Odell, Consulting Engineer, of an uncontrolled Shearer process drum-mix asphalt plant owned by Page Paving Company. This plant is unusual in that the asphalt cement is added to the aggregate before it enters the drum mixer. The total mass emissions from the process were determined utilizing a modified version of EPA Method 5 with the filter installed downstream of the third impinger. This modification was made to reduce plugging of the filter with asphaltic material, which occurred in the normal configuration. A crude determination of particle size was made by microscopically examining a sample of the particulate collected on one of the filters (Run 1). A

TABLE 3-8. SUMMARY OF PARTICLE SIZE DATA FOR SLOAN CONSTRUCTION COMPANY[44]
Data Rating: B

Particle size (μmA)[a]	Inlet to scrubber[b] Percent by weight	Inlet to scrubber[b] Emission rate (lb/hr)	Outlet from scrubber[c] Percent by weight	Outlet from scrubber[c] Emission rate (lb/hr)
30 and larger	27.7	596	54.8	99.2
9.2 - 30	19.0	409	9.2	16.6
5.5 - 9.2	14.8	318	8.3	15.0
3.3 - 5.5	13.3	286	4.7	8.5
2.0 - 3.3	12.2	262	4.4	8.0
1.0 - 2.0	9.5	204	4.9	8.9
0.3 - 1.0	2.3	50	8.0	14.5
0.1 - 0.3	0.7	15	5.7	10.3
Total		2,135		181.0

[a] Aerodynamic diameter.

[b] Downstream of a cyclone collector. Data taken from page 8 of test report (Appendix C).

[c] Outlet of a spray tower. Data taken from page 8 of test report (Appendix C).

TABLE 3-9. SUMMARY OF PARTICLE SIZE DATA FOR HARRISON, INC.[45]
Data Rating: B

Particle size (μmA)[a]	Inlet to scrubber[b] Percent by weight	Inlet to scrubber[b] Emission rate (lb/hr)	Outlet from scrubber[c] Percent by weight	Outlet from scrubber[c] Emission rate (lb/hr)
30 and larger	23.1	396.2	3.0	1.9
5.5 - 30	26.9	461.3	2.2	1.4
2.0 - 5.5	35.1	602.0	6.8	4.3
Smaller than 2.0	14.9	255.5	88.0	55.4
Total	100	1,715.0	100	63.0

[a] Aerodynamic diameter.

[b] Downstream of a cyclone collector. Data taken from page 6 of test report (Appendix C).

[c] Outlet of a centrifugal scrubber. Data taken from page 6 of test report (Appendix C).

log-normal distribution was constructed from this particle size data using a number of somewhat questionable assumptions.

The information contained in Reference 10 is well documented and includes adequate detail for evaluation. The method used to determine particle size is, however, inappropriate for any type of quantitative analysis. For this reason, Reference 10 was not used in the development of candidate emission factors, and no copy of such is included in this document.

3.4.5 Reference 12 (1973)

Reference 12 is the 1973 version of the Air Pollution Engineering Manual published by the Los Angeles County APCD. This document contains one additional data set (Test No. C-537) which was not included in Reference 1. This data set provides a characterization of the emissions from a 6,000-lb capacity asphalt batch plant equipped with a low efficiency cyclone, a multicyclone (multiple small diameter cyclones), and a multiple centrifugal scrubber. The particle size distribution was obtained for the dryer exhaust, the vent line from the scavenger system, downstream of the primary cyclone, and at the inlet to the scrubber. A summary of the data for Test No. C-537 contained in Reference 12 is provided in Table 3-10 with applicable sections of the document included in Appendix D.

Since the particle size data contained in Reference 12 is of the same vintage as that described previously for Reference 1, an identical rating of D was assigned to it.

3.4.6 Reference 23 (1976)

Reference 23 is a report of source tests conducted by an EPA contractor to measure the emissions from an experimental drum-mix plant processing recycled asphalt pavement. Particulate emissions from the plant were controlled by a venturi scrubber and associated inertial separator for mist elimination. Concurrent tests were conducted at both the inlet and outlet of the scrubber using EPA Method 5 or a modified version of EPA Method 8.

Three separate operating conditions were tested. The first operating scenario (one test) consisted of the introduction of the recycle material at the midpoint of the drum mixer. During the second operating condition (three tests) recycle material was introduced at the burner end of the drum along with the virgin aggregate. The final operating condition (three tests) consisted of injection of the recycle material at the burner end but with the inclination of the drum increased from 2 to 2.98 degrees. Particle sizing was performed during the second and third conditions using an Andersen 9-stage cascade impactor and a standard EPA Method 5 sampling train.

The only data in Reference 23 which are applicable to current process technology for the recycling of asphalt pavement are that obtained during the first operating condition (see Section 2.2.4). Since no determination of particle size was conducted during this test, only the data for total mass would be of value in this analysis. Due to the fact that the plant was experimental in nature and only one test was actually conducted for

TABLE 3-10. SUMMARY OF PARTICLE SIZE DATA FOR TEST C-537 - REFERENCE 12[26]

Data Rating: D[a]

Particle size range (μm)[b]	Vent line[c] (wt %)	Dryer exhaust[c] (wt %)	Inlet to primary cyclone[d] (wt %)	Inlet to multiclone[e] (wt %)	Inlet to scrubber[e] (wt %)
0-5	18.8	9.2	6.2	19.3	57.0
5-10	27.6	12.3	9.4	31.9	34.0
10-20	40.4	22.7	13.8	31.6	8.8[f]
20-50	12.1	49.3	22.9	15.1	0.2[f]
> 50	1.1	6.5	47.7	2.1	Nil

a Assumed identical to Reference 1.

b Stoke's diameter.

c Includes only particles < 200 mesh (74 μm). Data taken from Table 94, p. 328 of reference document.

d Combined effluent of dryer exhaust and vent line. Data taken from Table 96, p. 333 of reference document.

e Data taken from Table 96, p. 333 of reference document (Appendix D).

f Percentage of particles 20-50 μmS in diameter are reported in Table 96 (Appendix D) as 9.2%. This is obviously a typographical error since the total calculates out to be 109%. Appropriate correction has been made in the analysis for particles in this size range.

total mass, the information contained in Reference 23 was not used in the development of candidate emission factors. Although the data are generally unsatisfactory, the test results may be somewhat useful in estimating the emissions from this type of facility. Therefore, a copy of the test data for Reference 23 has been included in this report as Appendix E.

3.4.7 Reference 26 (1978)

Reference 26 is a study of the fine particle emissions from a variety of sources in the South Coast Air Basin (Los Angeles), conducted by a contractor to the California Air Resources Board (CARB). One test included in this study was of the emissions from an asphalt batch plant controlled by a cyclone collector followed by a baghouse. Only one test run was performed during the sampling program with concurrent measurements made at the inlet and outlet of the baghouse collector.

The size distribution of the particulate was determined at each sampling location using either of two sampling trains equipped with a series of three individual cyclones having nominal cut-points of 10, 3, and 1 μmA, respectively. For inlet testing, a standard EPA Method 5 (Joy) train was adapted for the program by installing the three cyclones and a backup filter in the oven section of the impinger box. For testing at the outlet, the Source Assessment Sampling System (SASS) was used. The data obtained from the CARB study were entered into the EADS system from which a printout was obtained. A summary of the data contained in Reference 26 is provided in Table 3-11 with a copy of the pertinent sections of the draft report included in Appendix F. Upon checking with the contractor it was learned that the test data for run 29S were not changed in the final report from that included in the draft shown in Appendix F.[48]

TABLE 3-11. SUMMARY OF PARTICLE SIZE DATA FOR REFERENCE 26[a]

Data Rating: B

Test No.	Sampling location[b]	Percent of particles in stated size range[c]			
		> 10 μmA	10-3 μmA	3-1 μmA	< 1 μmA
29S	Outlet	60	6	4	30

[a] From page 4-165 of Reference 26 (Appendix F).
[b] Location relative to baghouse collector.
[c] Aerodynamic diameter.

From the analysis of Reference 26 it was determined that the particle size measurements were made using sound methodology, and it does contain adequate information for validation. The only significant problem found

with the data was that the cyclone train at the inlet to the baghouse became overloaded with material, which could significantly affect the validity of the test results. This fact was learned from a review of the test report itself rather than from the EADS printout. For this reason, the data collected at the inlet of the baghouse were not used in the development of candidate emission factors. Since only one test run was conducted at the outlet of the baghouse, a rating of B was assigned to the data.

3.4.8 Reference 27 (1982)

Reference 27 is a report of the tests conducted by MRI, under the IP program, of a drum-mix asphalt plant controlled by a baghouse collector. The drum mixer was equipped to process recycled asphalt paving utilizing a split feed arrangement. Particulate matter contained in the exhaust stream was sampled at both the inlet and outlet of the baghouse with measurements also made of the condensation aerosol which would theoretically be formed upon release into the atmosphere (condensable organics).

The general sampling protocol used in this study was that developed for the IP program.[35] At the inlet, the total uncontrolled emissions from the process were determined from a six-point traverse utilizing EPA Method 5. The particle size distribution was obtained from samples collected by an Andersen High Capacity Stack Sampler equipped with a Sierra Instruments 15-μmA preseparator. Four particle size tests were conducted at each of the four sampling quadrants for a total of 16 test runs.

At the outlet from the baghouse, the total mass emissions from the plant were determined utilizing proposed EPA Method 17, with two tests being conducted at each of four sampling quadrants. The particle size distribution was likewise obtained using an Andersen Mark III cascade impactor and Sierra Instruments 15 μmA preseparator utilizing an identical test protocol.

Condensable organics testing was also performed during the study utilizing the Dilution Stack Sampling System (DSSS) developed by Southern Research Institute.[49] This system extracts a small slipstream of gas from the stack which, after removing particles > 2.5 μmA in diameter, is mixed in a dilution chamber with cool, dry ambient air. A standard high-volume air sampler is installed at the discharge end of the chamber which collects a combination of the fine particulate (< 2.5 μm) extracted from the stack and any new particulate matter formed by condensation. The loadings obtained from the DSSS are then compared to those measured by a second sampling train without the dilution chamber to determine the amount of condensable organics formed. Three separate tests were conducted at the outlet of the baghouse collector during the sampling program.

Tables 3-12 through 3-14 provide a summary of the results of this study with a copy of applicable portions of the document included in Appendix G. Since the tests in Reference 27 were conducted according to the protocol developed for the IP program and are well documented, a rating of A was assigned to the data.

TABLE 3-12. SUMMARY OF PARTICLE SIZE TEST DATA COLLECTED AT THE BAGHOUSE INLET - REFERENCE 27[a]

Data Rating: A

Test No.	Run No. (source-run-quad)	15-μm Cyclone Mass (mg)	15-μm Cyclone D_{50} size (μm)	15-μm Cyclone Cum. % less than stated size	Stage 1 Mass (mg)	Stage 1 D_{50} size (μm)	Stage 1 Cum. % less than stated size	Stage 2 Mass (mg)	Stage 2 D_{50} size (μm)	Stage 2 Cum. % less than stated size	Cyclone Mass (mg)	Cyclone D_{50} size (μm)	Cyclone Cum. % less than stated size	Filter Mass (mg)	Filter D_{50} size (μm)
1	I-1-1(B)	4,775.2	14.8	30.2	95.2	11.4	28.8	617.5	6.3	19.7	1,091.0	1.9	3.8	258.0	< 1.9
	I-1-2	6,088.7	15.5	25.0	125.0	11.8	23.5	566.6	6.7	16.5	1,143.3	1.9	2.4	198.0	< 1.9
	I-1-3	6,345.5	15.1	19.2	68.5	11.5	18.3	399.4	6.5	13.3	906.8	1.9	1.7	134.3	< 1.9
	I-1-4	10,607.6	15.2	17.6	179.5	11.6	16.2	750.9	6.5	10.4	977.9	1.9	2.8	356.5	< 1.9
2	I-2-1(C)[b]	212.91	14.5	26.7	45.6	11.2	25.1	221.8	6.2	17.5	446.3	1.8	2.1	60.8	< 1.8
	I-2-2(B)	5,881.3	15.6	25.7	127.0	11.7	24.1	621.1	6.6	16.2	1,061.0	2.0	2.8	222.6	< 2.0
	I-2-3	4,157.7	15.4	22.9	60.4	11.7	21.7	362.7	6.6	15.0	746.8	1.9	1.2	62.4	< 1.9
	I-2-4	9,068.9	15.0	22.9	406.6	11.5	19.5	767.3	6.4	12.9	1,038.8	1.9	4.1	481.7	< 1.9
3	I-3-1	5,718.0	15.7	22.3	364.8	11.7	17.4	200.5	6.6	14.7	975.1	2.0	1.4	104.1	< 2.0
	I-3-2	6,113.0	15.5	23.5	81.0	11.7	22.5	505.7	6.6	16.2	997.5	2.0	3.7	294.8	< 2.0
	I-3-3	3,086.1	15.4	33.5	62.2	11.6	32.1	393.8	6.5	23.6	937.4	1.9	3.4	159.4	< 1.9
	I-3-4	10,346.7	15.2	19.8	170.5	11.6	18.5	888.7	6.5	11.6	1,062.2	1.9	3.4	435.3	< 1.9
4	I-4-1	2,149.4	15.5	35.8	48.4	11.7	34.4	301.8	6.61	25.4	671.9	2.0	5.3	177.1	< 2.0
	I-4-2	3,242.0	15.4	27.8	78.4	11.7	26.00	348.8	6.6	18.2	642.8	1.9	3.9	175.2	< 1.9
	I-4-3	7,794.4	15.4	20.2	89.3	11.6	19.3	550.6	6.6	13.6	874.2	1.9	4.7	456.6	< 1.9
	I-4-4	9,585.9	15.5	21.4	178.5	11.7	20.0	873.4	6.6	12.8	785.0	2.0	6.4	777.3	< 2.0

[a] Reproduced from Table 4.4, p. 49 of Reference 27 (Appendix G).

[b] Test conducted during the processing of recycled asphalt paving.

TABLE 3-13. SUMMARY OF PARTICLE SIZE TEST DATA COLLECTED AT THE BAGHOUSE OUTLET - REFERENCE 27[a]

Data Rating: A

Test No.	Run No. (source-run-quad)	15-μm Cyclone Mass (mg)	15-μm Cyclone D_{50} size (μm)	15-μm Cyclone Cum. % less than stated size	Stage 0 Mass (mg)	Stage 0 D_{50} size (μm)	Stage 0 Cum. % less than stated size	Stage 1 Mass (mg)	Stage 1 D_{50} size (μm)	Stage 1 Cum. % less than stated size	Stage 2 Mass (mg)	Stage 2 D_{50} size (μg)	Stage 2 Cum. % less than stated size	Stage 3 Mass (mg)	Stage 3 D_{50} size (μg)	Stage 3 Cum. % less than stated size
1	0-1-1(B)	37.96	14.9	42.1	0.41	14.7	41.5	1.34	9.1	39.5	3.65	6.2	33.9	5.30	4.2	25.8
	0-1-2[b]	84.91	14.7	21.0	0.51	14.4	20.1	0.89	9.0	19.7	3.94	6.1	16.0	4.44	4.1	11.9
	0-1-3[b]	39.29	14.9	26.0	0.00	14.6	26.0	0.63	9.1	24.8	1.95	6.1	21.1	2.82	4.2	15.8
	0-1-4	72.37	14.8	31.6	0.61	14.7	31.1	0.73	9.2	30.4	2.36	6.2	28.1	16.29	4.2	12.7
2	0-2-1	21.93	15.2	56.7	1.60	14.9	53.1	1.88	9.3	49.8	4.33	6.3	41.2	4.56	4.3	32.2
	0-2-2	49.78	15.0	35.7	0.67	14.7	34.9	0.85	9.2	33.8	3.36	6.2	29.4	4.33	4.2	23.8
	0-2-3	61.54	14.6	32.8	3.52	14.3	28.9	1.98	8.9	26.8	4.77	6.0	21.6	4.58	4.1	16.6
	0-2-4	71.68	15.4	37.0	7.79	15.0	30.1	3.38	9.4	27.2	5.75	6.3	22.1	6.57	4.3	16.3

Test No.	Run No. (source-run-quad)	Stage 4 Mass (mg)	Stage 4 D_{50} size (μm)	Stage 4 Cum. % less than stated size	Stage 5 Mass (mg)	Stage 5 D_{50} size (μm)	Stage 5 Cum. % less than stated size	Stage 6 Mass (mg)	Stage 6 D_{50} size (μm)	Stage 6 Cum. % less than stated size	Stage 7 Mass (mg)	Stage 7 D_{50} size (μg)	Stage 7 Cum. % less than stated size	Filter Mass (mg)	Filter D_{50} size (μg)
1	0-1-1(B)	8.45	2.7	12.9	5.71	1.3	4.2	2.07	0.80	1.1	0.33	0.59	0.56	0.37	< 0.59
	0-1-2[b]	5.43	2.6	6.8	4.74	1.3	2.4	1.71	0.78	0.82	0.57	0.58	0.29	0.31	< 0.58
	0-1-3[b]	2.97	2.7	10.2	3.26	1.3	4.1	1.81	0.79	0.64	0.21	0.58	0.24	0.13	< 0.58
	0-1-4	0.00	2.7	12.7	12.4	1.3	1.0	0.00	0.81	1.0	0.88	0.59	0.20	0.21	< 0.59
2	0-2-1	5.68	2.7	21.0	5.09	1.3	11.0	2.60	0.81	5.8	1.54	0.60	2.8	1.40	< 0.60
	0-2-2	7.91	2.7	13.6	6.63	1.3	5.1	2.95	0.80	1.3	0.77	0.59	0.26	0.20	< 0.59
	0-2-3	7.04	2.6	8.9	5.09	1.3	3.3	2.45	0.78	0.64	0.46	0.57	0.14	0.13	< 0.57
	0-2-4	8.35	2.8	9.0	6.07	1.4	3.7	2.52	0.82	1.4	0.91	0.61	0.63	0.72	< 0.61

[a] Reproduced from Table 4.5, p. 50 of Reference 27 (Appendix G).

[b] Test conducted during the processing of ~ 30% recycled asphalt paving.

TABLE 3-14. PARTICULATE MASS CONCENTRATIONS (CONDENSABLES TESTING) - REFERENCE 27[a]

Data Rating: A

Run No.	Cyclone X > 15 μ mg/dscm[b]	Cyclone X > 15 μ gr/dscf[c]	Cyclone III 2.5-15 μm mg/dscm[b]	Cyclone III 2.5-15 μm gr/dscf[c]	Filter < 2.5 μm mg/dscm[b]	Filter < 2.5 μm gr/dscf[c]	Filter plus wash < 2.5 μm condensables mg/dscm[b]	Filter plus wash < 2.5 μm condensables gr/dscf[c]	% Condensables	Total emissions mg/dscm[b]	Total emissions gr/dscf[c]
1 IP	5.78	0.00252	1.57	0.000686	1.59	0.000694				8.94	0.0039
1 SDSS	19.03	0.00831	2.80	0.00122			-	-	-	-	-
2 IP	18.76	0.00819	0.94	0.00041	1.49	0.000651				21.19	0.0093
2 SDSS	14.92	0.00652	2.01	0.000878			15.78	0.00689	43.7	32.71	0.0143
3 IP	36.74	0.16	4.36	0.0019	1.66	0.000725				42.76	0.0187
3 SDSS	25.61	0.112	5.52	0.00241			19.79	0.00864	35.6	50.92	0.0223
4 IP	9.70	0.00424	2.14	0.000935	2.42	0.00106				14.26	0.0062
4 SDSS	14.47	0.00632	2.13	0.00093			27.81	0.0121	57.2	44.41	0.0194
Average IP	17.75	0.00775	2.25	0.000983	1.79	0.000782				21.79	0.0095
Average SDSS	18.51	0.00808	3.11	0.00136			21.13	0.00923	45.3	42.68	0.0187

[a] Reproduced from Table 5.4, p. 81 of Reference 27 (Appendix G). Tests conducted during the processing of ~ 30% recycled asphalt paving.

[b] Milligrams per dry standard cubic meter.

[c] Grains per dry standard cubic foot.

3.5 DEVELOPMENT OF CANDIDATE EMISSION FACTORS

3.5.1 Data Analysis Methodology

The information contained in Tables 3-3 through 3-11 was reduced to a common format using a family of computer programs developed especially for this purpose (as shown in Table 3-15). These programs are fundamentally BASIC translations of the FORTRAN program SPLIN2 developed by Southern Research Institute.[50] The particular version translated is one that MRI earlier modified to operate utilizing as few as three data points. Additional changes were made to produce emission factors as functions of the aerodynamic particle diameter.

TABLE 3-15. COMPARISON OF COMPUTER PROGRAMS

Fitted size distribution	JSKPRG Spline	JSKRAW Spline	JSKLOG Log-normal
Input requirements: particle size data	Cumulative mass fractions; particle density	Largest particle diameter; incremental mass fractions; particle density	Completed log-normal size distribution
process data	Process and emission rates - or - emission factor	Process and emission rates - or - emission factor	Process and emission rates
Output:	Size-specific emission factors (English and metric units) for selected aerodynamic particle diameters		

As mentioned above, SPLIN2 is the central portion of the program which uses the so-called "spline" fits. Spline fits result in cumulative mass size distributions very similar to those which would be drawn using a French curve and fully logarithmic graph paper. In effect, the logarithm of cumulative mass is plotted as a function of the logarithm of the particle size, and a smooth curve with a continuous, nonnegative derivative is drawn.

The process by which this smooth cumulative distribution is constructed involves passing an interpolation parabola through three measured data points at a time. The parabola is then used to interpolate additional points between measured values. When the set of interpolated points are added to the original set of data, a more satisfactory fit is obtained than would be the case using only the measured data.

The primary addition to the spline fitting procedure is the determination of size-specific emission factors once the size distribution is obtained by a spline fit. The user is prompted to input process and emission rate data. The program determines a total particulate emission factor by:

$$E_{TP} = \frac{e_{TP}}{R} \qquad (7)$$

where: E_{TP} = total particulate emission factor (lb/ton)

e_{TP} = total particulate emission rate (lb/hr)

R = process weight rate (tons of asphalt paving produced/hr)

Emission factors for each size range are then obtained by multiplying E_{TP} by the mass fraction associated with that range. The programs automatically convert the size-specific emission factors obtained from English units (lb/ton) to the appropriate metric units (kg/metric ton), which is tabulated as a part of the output format (1 kg/metric ton = 1 kg/10^6 g = 1 kg/Mg).

As an additional function, each program has the capability of converting from Stoke's diameter to aerodynamic diameter using the appropriate density correction (Table 3-1). For data reduction purposes, a density of 2.4 g/cm^3 was assumed unless otherwise specified in the reference document.

Some of the programs also require that a largest particle diameter be provided to complete the size distribution. A maximum size of 74 μm (Stoke's diameter) was assumed unless other data were available (see Section 3.5.2). This value was selected due to the apparent correlation of the amount of material < 200 mesh contained in the aggregate with the total mass emissions from the process.[51] It was likewise assumed that particle sizing by dry sieving generated data by Stoke's rather than physical diameter. A complete listing of each program is provided in Appendix H with sample outputs shown in Figures 3-1 to 3-3.

SPLIN2 PROGRAM - 02/22/82 V1

TEST ID: EXAMPLE OUTPUT OF "JSKPRG"

INPUT DATA: PROCESS WEIGHT RATE = 100 TONS PROD./HR
TOTAL PARTICULATE EMISSION RATE = 100 LB/HR
PARTICLE DENSITY = 2.44 G/CC

MEASURED SIZE DISTRIBUTION

CUT(um)	CUM. % < CUT
10	15
20	25
30	34
50	50

OUTPUT DATA: TP EMISSION FACTOR = 1 LB/T (.5 KG/MT)

CUT (umA)	CUM. % < CUT	EMISSION FACTOR (LB/T)	(KG/MT)
.625	1.78801	.0178801	8.94006E-03
1	2.3787	.023787	.0118935
1.25	2.73215	.0273215	.0136607
2.5	4.25364	.0425364	.0212682
5	6.74744	.0674744	.0337372
10	10.9053	.109053	.0545267
15	14.567	.14567	.0728348
20	17.9582	.179582	.0897908

END OF TEST SERIES

Figure 3-1. Example output of "JSKPRG."

SPLIN2 PROGRAM - 02/22/82 V1

TEST ID: EXAMPLE OUTPUT OF "JSKRAW"

INPUT DATA: PROCESS WEIGHT RATE = 100 TONS PROD. /HR
TOTAL PARTICULATE EMISSION RATE = 100 LB/HR
PARTICLE DENSITY = 2.44 G/CC

MEASURED PARTICLE SIZE DISTRIBUTION

CUT (um)	RAW % < CUT	CUM. % < CUT
10	15	15
20	10	25
30	9	34
50	16	50
74	50	100

OUTPUT DATA: TP EMISSION FACTOR = 1 LB/T (.5 KG/MT)

CUT (umA)	CUM. % < CUT	EMISSION FACTOR (LB/T)	(KG/MT)
.625	1.78804	.0178804	8.94021E-03
1	2.37873	.0237873	.0118937
1.25	2.73218	.0273218	.0136609
2.5	4.25366	.0425366	.0212683
5	6.74745	.0674745	.0337373
10	10.9053	.109053	.0545267
15	14.567	.14567	.0728348
20	17.9581	.179581	.0897907

END OF TEST SERIES

Figure 3-2. Example output of "JSKRAW."

SPLIN2 PROGRAM - 02/22/82 V1

TEST ID: EXAMPLE OUTPUT OF "JSKLOG"

INPUT DATA: PROCESS WEIGHT RATE = 100 TONS PROD./HR
TOTAL PARTICULATE EMISSION RATE = 100 LB/HR
PARTICLE DENSITY = 2.44 G/CC

MEASURED SIZE DISTRIBUTION

CUT(um)	CUM. % < CUT
10	15
20	25
30	34
50	50

OUTPUT DATA: TP EMISSION FACTOR = 1 LB/T (.5 KG/MT)

CUT (umA)	CUM. % < CUT	EMISSION FACTOR (LB/T)	(KG/MT)
.625	1.788	.01788	8.94E-03
1	2.379	.02379	.011895
1.25	2.732	.02732	.01366
2.5	4.254	.04254	.02127
5	6.747	.06747	.033735
10	10.9	.109	.0545
15	14.57	.1457	.07285
20	17.96	.1796	.0898

THIS DATA SET WAS FIT TO A LOG-NORMAL SIZE DISTRIBUTION

Figure 3-3. Example output of "JSKLOG."

Since the spline fit routine was originally designed for a cascade impactor data reduction system, its application to noninertial particle sizing methods may not always be entirely appropriate. Often a large scale extrapolation (i.e., order of magnitude) of the data will result in a negative slope of the cumulative size distribution curve. In such cases, JSKLOG was used in its place. In JSKLOG, the data input to the program have already been fitted to a standard log-normal distribution utilizing a separate program written for the Texas Instruments Model 59 (TI-59) programmable calculator. This program was used whenever a spline fit was determined not suitable to represent adequately the distribution in the smaller particle size ranges. A complete description and listing of the TI-59 program used to compute the necessary log-normal distributions are provided in Appendix I.

3.5.2 Results of Data Analysis

Each of the specific data sets described above were processed through the appropriate computer program to obtain both the particle size distribution and size-specific emission factors for selected particle diameters. Copies of the individual computer printouts have been included in Appendix J, with the results of the computer analyses summarized in Tables 3-16 through 3-29. Any calculations needed to convert the raw data to the proper format for input to the computer were conducted manually, and copies of such calculations are also included in Appendix J. In the case of Reference 27, the test results were already analyzed by the spline routine as part of the study and thus, no further data reduction was necessary. The tabular data presented in the test report were simply reproduced in Tables 3-27 and 3-28.

A number of notations should be made regarding the particle size data shown in Tables 3-16 through 3-29. First, only data for particles larger than 2.5 μm (aerodynamic diameter) have been reported even though the spline equation was asked to predict values below that size range. This particular lower cut off was selected since the last measured data point was, in most cases, 5 or 10 μm. Extrapolating the size distribution below 2.5 μm without the benefit of actual data is questionable and cannot be considered good engineering practice. In addition, the size-specific emission factors calculated from the test data have also been reported in each table even though they were not actually used in the development of the candidate emission factors for the process. These values have been included only for the sake of comparison.

In the case of test No. 426 (Reference 1), only selected portions of the raw particle size data were used as input to the SPLIN2 program. The data for > 60 μmS and for 3 and 4 μmS were intentionally deleted from the computer analysis. Only data for particles < 60 μmS were used since the remainder of the distribution was derived from a sieve analysis of the coarse particles which does not yield test results which are based on a true Stoke's diameter. For 3 and 4 μmS particles, the data were deleted since they were generally so closely spaced that the spline fit routine may not have yielded physically valid results. It is felt that the above deletions did not introduce any significant bias in the output from the SPLIN2 program since the entire size distribution was essentially log-normal.

TABLE 3-16. CALCULATED PARTICLE SIZE DISTRIBUTIONS AND CONTROLLED EMISSION FACTORS FOR REFERENCE 1 - SCRUBBER INLET[a]

Data Rating: D

Test ID No.[b]	Cumulative mass % equal to or less than stated size[c]					Cumulative emission factor equal to or less than stated size (kg/Mg)[d]					
	2.5 µmA	5.0 µmA	10.0 µmA	15.0 µmA	20.0 µmA	2.5 µmA	5.0 µmA	10.0 µmA	15.0 µmA	20.0 µmA	Total mass emission factor
C-369	49.5	60.6	70.8	75.9	79.0	0.771	0.943	1.10	1.18	1.23	1.56
C-372A	19.2	37.7	62.1	76.6	85.7	0.0461	0.0907	0.149	0.184	0.206	0.241
C-372B	46.4	64.3	81.7	90.2	95.0	0.196	0.272	0.346	0.382	0.402	0.423

[a] From computer printouts included in Appendix J, pages J-3, 5, and 7.

[b] Measured at inlet to a multiple centrifugal scrubber. Test C-422(1) not included due to lack of size-specific test data.

[c] Aerodynamic diameter.

[d] Kilograms of particulate matter per 10^6 g (Mg) of asphalt concrete produced.

TABLE 3-17. CALCULATED PARTICLE SIZE DISTRIBUTIONS AND CONTROLLED EMISSION FACTORS FOR REFERENCE 1 - SCRUBBER OUTLET[a]

Data Rating: D

Test ID No.[b]	Cumulative mass % equal to or less than stated size[c]					Cumulative emission factor equal to or less than stated size (kg/Mg)[d]					
	2.5 µmA	5.0 µmA	10.0 µmA	15.0 µmA	20.0 µmA	2.5 µmA	5.0 µmA	10.0 µmA	15.0 µmA	20.0 µmA	Total mass emission factor
C-369	62.9	70.3	76.6	79.6	81.5	0.0679	0.0758	0.0827	0.0860	0.0879	0.108
C-372A	57.1	68.3	78.0	82.6	85.2	0.0181	0.0216	0.0247	0.0261	0.0270	0.0316
C-372B	69.5	74.9	79.5	81.8	83.2	0.0467	0.0503	0.0534	0.0549	0.0559	0.0672
C-422(1)	56.4	63.1	69.5	72.9	75.1	0.0379	0.0424	0.0467	0.0490	0.0505	0.0672

[a] From computer printouts included in Appendix J, pages J-4, 6, 8, and 9.

[b] Emissions to atmosphere from a multiple centrifugal scrubber.

[c] Aerodynamic diameter.

[d] Kilograms of particulate matter per 10^6 g (Mg) of asphalt concrete produced.

TABLE 3-18. CALCULATED PARTICLE SIZE DISTRIBUTION AND CONTROLLED EMISSION FACTORS FOR REFERENCE 1 - TEST NO. C-393[a]

Data Rating: D

Particle size (μmA)[b]	Cumulative mass % equal to or less than stated size	Cumlative emission factor equal to or less than stated size (kg/Mg)[c]
2.5	$1.12\ (10)^{-4}$	$2.59\ (10)^{-5}$
5.0	0.0449	0.0104
10.0	2.8	0.646
15.0	13.9	3.21
20.0	30.8	7.11
Total mass emission factor		23.1

[a] From computer printout included in Appendix J, page J-13. Measured at the inlet of a baffle-plate scrubber. Outlet data eliminated from analysis.

[b] Aerodynamic diameter.

[c] Kilograms of particulate matter per 10^6 g (Mg) of asphalt concrete produced.

TABLE 3-19. CALCULATED PARTICLE SIZE DISTRIBUTION AND CONTROLLED EMISSION FACTORS FOR REFERENCE 1 - TEST NO. C-426[a]

Data Rating: D

Measurement location	Cumulative mass % equal to or less than stated size[b]					Cumulative emission factor equal to or less than stated size (kg/Mg)[c]					
	2.5 µmA	5.0 µmA	10.0 µmA	15.0 µmA	20.0 µmA	2.5 µmA	5.0 µmA	10.0 µmA	15.0 µmA	20.0 µmA	Total mass emission factor
Cyclone inlet	0.803	4.56	13.7	20.4	25.2	0.148	0.839	2.53	3.76	4.64	18.41
Cyclone outlet[d]	0.833	2.93	6.92	9.96	12.6	0.0600	0.211	0.500	0.717	0.908	7.20
Vent line[e]	1.63	8.87	26.0	38.4	47.7	0.00896	0.488	1.43	2.11	2.62	5.49

[a] From computer printouts included in Appendix J, pages J-10 through J-12.

[b] Aerodynamic diameter.

[c] Kilograms of particulate matter per 10^6 g (Mg) of asphalt concrete produced.

[d] Inlet to multiple centrifugal scrubber. Includes effluent from cyclone and vent line.

[e] Effluent from scavenger system.

TABLE 3-20. STOKE'S DIAMETER VERSUS SETTLING VELOCITY FOR PARTICLES OF VARYING DENSITY - REFERENCE 3[a]

Settling velocity[b] (cm/sec)	Stoke's diameter for particles of specified density[c] 2.4 g/cm³	2.5 g/cm³	2.6 g/cm³	2.7 g/cm³	2.8 g/cm³	2.9 g/cm³
0.2	5.3	5.2	5.1	5.0	4.9	4.8
0.4	7.5	7.4	7.2	7.1	6.9	6.8
0.8	10.6	10.4	10.2	10.0	9.8	9.6
1.6	15.0	14.7	14.4	14.1	13.9	13.6
3.2	21.2	20.8	20.4	20.0	19.6	19.2
6.4	30.0	29.4	28.8	28.3	27.7	27.2
12.8	42.4	41.6	40.8	40.0	39.2	38.4
25.6	60.0	58.8	57.7	56.6	55.4	54.3

[a] From calculations included in Appendix J, pages J-15 through 19.

[b] Assumes dry air at 20°C and 760 mm Hg.

[c] Calculated from Eq. (5) with $\eta = 1814\ (10)^{-7}$ g/cm·sec; $g = 980.665$ cm/sec²; $\rho' = 1.2046\ (10)^{-3}$ g/cm³; and ρ = to the values shown in each column.

TABLE 3-21. CALCULATED PARTICLE SIZE DISTRIBUTIONS AND UNCONTROLLED EMISSION FACTORS FOR REFERENCE 3 - DRYER EXHAUST[a]

Data Rating: C

Plant ID	Cumulative mass % equal to or less than stated size[b]					Cumulative emission factor equal to or less than stated size (kg/Mg)[c]					
	2.5 μmA	5.0 μmA	10.0 μmA	15.0 μmA	20.0 μmA	2.5 μmA	5.0 μmA	10.0 μmA	15.0 μmA	20.0 μmA	Total mass emission factor
A4	0.774	4.29	13.9	21.6	26.3	0.0728	0.403	1.31	2.02	2.47	9.4
D1	0.0803	1.67	10.4	16.9	20.9	0.0169	0.351	2.18	3.55	4.38	21.0
H2	0.0576	1.78	13.3	21.9	25.7	$7.08(10)^{-3}$	0.219	1.63	2.69	3.16	12.3
I2	3.03	6.86	12.6	16.1	21.5	0.639	1.45	2.66	3.40	4.53	21.1
I3	0.0502	2.34	22.0	38.0	45.7	$7.38(10)^{-3}$	0.344	3.23	5.59	6.72	14.7
D2	2.68	7.39	20.2	36.7	52.2	0.503	1.39	3.80	6.90	9.81	18.8
C1	0.138	1.81	10.4	19.7	26.3	0.0500	0.656	3.78	7.16	9.55	36.3
C2	0.0259	1.24	12.4	22.8	28.8	$9.34(10)^{-3}$	0.448	4.49	8.24	10.4	36.1
B3	0.197	1.40	6.02	11.1	15.6	0.0919	0.655	2.81	5.19	7.30	46.7
D4	1.25	6.33	21.8	37.7	48.9	0.933	4.72	16.2	28.1	36.5	74.6
F3	0.219	3.07	15.8	25.6	32.1	0.0807	1.13	5.84	9.46	11.8	36.9
G2	0.0633	1.54	14.0	32.3	44.9	0.0192	0.469	4.25	9.82	13.6	30.4
G1	$6.72(10)^{-3}$	0.647	11.0	25.9	32.5	$1.88(10)^{-3}$	0.180	3.08	7.23	9.06	27.9
B1	0.956	2.13	4.38	6.47	8.06	0.152	0.338	0.696	1.03	1.28	15.9
F2	2.96	8.76	20.5	30.1	38.0	0.432	1.28	2.99	4.40	5.54	14.6

[a] From computer printouts on pages J-20, 22, 24, 26, 28, 30, 32, 34, 36, 38, 40, 42, 44, 46, and 48 of Appendix J. Uncontrolled emissions from the dryer only.

[b] Aerodynamic diameter.

[c] Kilograms of particulate matter per 10^6 g (Mg) of asphalt concrete produced.

TABLE 3-22. CALCULATED PARTICLE SIZE DISTRIBUTIONS AND CONTROLLED EMISSION FACTORS FOR REFERENCE 3 - OUTLET OF PRIMARY COLLECTORS[a]

Data Rating: C

Plant ID	Cumulative mass % equal to or less than stated size[b]					Cumulative emission factor equal to or less than stated size (kg/Mg)[c]					
	2.5 µmA	5.0 µmA	10.0 µmA	15.0 µmA	20.0 µmA	2.5 µmA	5.0 µmA	10.0 µmA	15.0 µmA	20.0 µmA	Total mass emission factor
A4	5.00	9.60	16.7	22.1	26.5	0.0229	0.0440	0.0767	0.101	0.121	0.458
D1	2.38	6.02	12.4	17.3	21.0	0.0624	0.158	0.325	0.453	0.549	2.62
H2	7.45	11.8	17.9	22.5	26.2	0.0767	0.121	0.184	0.231	0.270	1.03
I2	0.397	2.23	8.52	15.6	22.2	0.00222	0.0125	0.0477	0.0876	0.125	0.560
I3	7.13	15.7	29.2	39.1	46.4	0.0998	0.219	0.409	0.547	0.650	1.40
D2	1.55	7.40	23.5	38.2	49.6	0.0583	0.279	0.886	1.44	1.87	3.77
C1	2.68	6.60	14.1	20.7	26.3	0.0474	0.117	0.250	0.366	0.465	1.77
C2	5.31	10.4	18.5	24.7	29.7	0.109	0.213	0.379	0.506	0.609	2.05
B3	0.622	2.29	6.74	11.5	16.0	0.00759	0.0279	0.0823	0.140	0.195	1.22
D4	4.48	12.5	27.6	39.3	48.1	0.465	1.30	2.87	4.09	5.00	10.4
F3	3.85	9.16	18.6	26.2	32.3	0.0905	0.215	0.437	0.616	0.760	2.35
G2	2.48	8.63	22.5	34.6	44.2	0.0764	0.266	0.694	1.07	1.36	3.08
K4[d]	-	-	-	-	-	-	-	-	-	-	-
G1	9.74	14.6	22.0	27.9	33.0	0.312	0.468	0.703	0.892	1.06	3.20
B1	1.74	3.02	5.04	6.67	8.07	0.00782	0.0136	0.0226	0.0299	0.0362	0.449
F2	5.14	12.0	23.1	31.1	36.8	0.0586	0.136	0.263	0.354	0.420	1.14

[a] From computer printouts on pages J-21, 23, 25, 27, 29, 31, 33, 35, 37, 39, 41, 43, 45, 47, and 49 of Appendix J. Emissions from dryer controlled by multiple cyclone dust collectors.

[b] Aerodynamic diameter.

[c] Kilograms of particulate matter per 10^6 g (Mg) of asphalt concrete produced.

[d] Data set deleted.

TABLE 3-23. CALCULATED PARTICLE SIZE DISTRIBUTIONS AND FACTORS FOR REFERENCE 8 - SLOAN[a]

Data Rating: B

Particle size μmA[b]	Cumulative mass % equal to or less than stated size		Cumulative emission factors equal to or less than stated size			
			Washer inlet[c]		Washer exhaust	
	Washer inlet[c]	Washer exhaust	lb/ton[d]	kg/Mg[d]	lb/ton[d]	kg/Mg[d]
2.5	17.6	20.5	1.67	0.834	0.165	0.0825
5.0	35.6	26.6	3.38	1.69	0.214	0.107
10.0	54.7	36.5	5.19	2.59	0.294	0.147
15.0	61.7	38.9	5.86	2.93	0.313	0.156
20.0	65.9	40.6	6.25	3.13	0.327	0.163
Total mass emission factor			9.49	4.74	0.804	0.402

[a] From computer printouts on pages J-51 and J-52 of Appendix J. Based on test data from Sloan Construction Company. Emissions controlled by a spray tower scrubber.

[b] Aerodynamic diameter.

[c] Exit from a single cyclone collector.

[d] Pounds of particulate matter per short ton (assumed) of asphalt concrete produced or kilograms of particulate matter per 10^6 g (Mg) of asphalt concrete produced.

TABLE 3-24. CALCULATED PARTICLE SIZE DISTRIBUTIONS AND EMISSION FACTORS FOR REFERENCE 8 - HARRISON[a]

Data Rating: B

Particle size μmA[b]	Cumulative mass % equal to or less than stated size		Cumulative emission factors equal to or less than stated size			
			Pre-wash entrance[c]		Washer exhaust	
	Pre-wash entrance[c]	Washer exhaust	lb/ton[d]	kg/Mg[e]	lb/ton[d]	kg/Mg[e]
2.5	20.7	89.8	1.97	0.986	0.314	0.157
5.0	45.5	94.3	4.34	2.17	0.330	0.165
10.0	62.6	95.8	5.97	2.98	0.335	0.168
15.0	68.1	96.2	6.48	3.24	0.337	0.168
20.0	71.7	96.5	6.83	3.41	0.338	0.169
Total mass emission factor			9.53	4.76	0.350	0.175

[a] From computer printouts on pages J-53 and J-54 of Appendix J. Based on test data from Harrison, Inc. Emissions controlled by a centrifugal scrubber.

[b] Aerodynamic diameter.

[c] Measured at exit from a single cyclone collector.

[d] Pounds of particulate matter per short ton (assumed) of asphalt concrete produced.

[e] Kilograms of particulate matter per 10^6 g (Mg) of asphalt concrete produced.

TABLE 3-25. CALCULATED PARTICLE SIZE DISTRIBUTIONS AND EMISSION FACTORS FOR REFERENCE 12 - TEST NO. C-537[a]

Data Rating: D

Test No.	Measurement location	Cumulative mass % equal to or less than stated size[b]					Cumulative emission factor equal to or less than stated size (kg/Mg)[f]					
		2.5 µmA	5.0 µmA	10.0 µmA	15.0 µmA	20.0 µmA	2.5 µmA	5.0 µmA	10.0 µmA	15.0 µmA	20.0 µmA	Total particulate
C-537	Inlet to primary cyclone[c]	0.726	2.94	8.91	14.9	20.0	0.115	0.464	1.41	2.35	3.16	15.8
C-537	Inlet to multiclone[d]	1.33	7.93	28.9	48.9	63.2	0.0584	0.350	1.27	2.16	2.79	4.41
C-537	Inlet to scrubber[e]	11.7	34.6	70.3	89.1	95.6	0.0400	0.118	0.240	0.305	0.327	0.342

[a] From computer printouts on Pages J-56, 57, and 58 of Appendix J.

[b] Aerodynamic diameter.

[c] Includes drier exhaust and vent line.

[d] Outlet from a single cyclone collector.

[e] Outlet from a multiple cyclone collector.

[f] Kilograms of particulate matter per 10^6 g (Mg) of asphalt concrete produced.

TABLE 3-26. CALCULATED PARTICLE SIZE DISTRIBUTION AND ASSOCIATED CONTROLLED EMISSION FACTORS FOR REFERENCE 26 - BAGHOUSE OUTLET[a]

Data Rating: B

Particle size[b] (μmA)	Cumulative mass % equal to or less than stated size	Cumulative emission factor[c] (kg/Mg)
2.5	33.2	0.00412
5.0	35.8	0.00443
10.0	40.4	0.0050
15.0	46.8	0.0058
20.0	53.9	0.00668
Total mass emission factor		0.0124

[a] From computer printouts on page J-61 of Appendix J. Inlet test data not processed.

[b] Aerodynamic diameter.

[c] Kilograms of particulate matter per 10^6 g (Mg) of asphalt concrete produced.

TABLE 3-27. CALCULATED EMISSIONS FACTORS FOR REFERENCE 27 - BAGHOUSE INLET[a]

Data Rating: A

Test No.	Run No. (source-run-quad)	Matching mass run	Total mass emission rate (lb/h)	Production rate[c] (ton/h)	Total mass emission factor[d] (lb/ton)	Size-specific emission factors[d] < 2.5 µm (lb/ton)	< 2.5 µm (kg/Mg)	< 10 µm (lb/ton)	< 10 µm (kg/Mg)	< 15 µm (lb/ton)	< 15 µm (kg/Mg)
1	I-1-1(B)	I-7	7,480	225	33.3	2.1	1.1	9.1	4.6	10.2	5.1
	I-1-2	I-1(C)	8,190	217	37.7	1.6	0.80	8.3	4.2	9.4	4.7
	I-1-3	I-2	6,930	162	42.8	1.4	0.70	7.5	3.8	8.3	4.2
	I-1-4	I-1(C)	8,190	217	37.7	1.5	0.75	5.6	2.8	6.7	3.4
2	I-2-1(B)[b]	None	-	-	(30.9)	1.3	0.65	7.4	3.7	8.5	4.3
	I-2-2(B)	I-2	6,930	162	42.8	1.9	0.95	9.5	4.8	10.9	5.5
	I-2-3	I-7	7,480	225	33.3	0.8	0.4	6.8	3.4	7.6	3.8
	I-2-4	I-5	7,180	195	36.8	2.0	1.0	6.6	3.3	8.5	4.3
3	I-3-1	I-8	5,840	215	27.2	0.75	0.38	4.5	2.3	5.8	2.9
	I-3-2	I-7	7,480	225	33.3	1.8	0.90	7.1	3.6	7.8	3.9
	I-3-3	I-8	5,840	215	27.2	1.6	0.80	8.3	4.2	9.1	4.6
	I-3-4	I-7	7,480	225	33.3	1.5	0.75	5.7	2.9	6.6	3.3
4	I-4-1[b]	None	-	-	(30.9)	2.5	1.3	10.0	5.0	11.0	5.5
	I-4-2	I-6(B)	5,720	205	27.9	1.6	0.80	6.8	3.4	7.7	3.9
	I-4-3[b]	None	-	-	(30.9)	1.9	0.95	5.6	2.8	6.3	3.2
	I-4-4[b]	None	-	-	(30.9)	2.2	1.1	5.6	2.8	6.6	3.3
		Non-matching mass runs									
		I-3	5,620	223	25.2						
		I-4	3,850	237	16.3						
Total average			6,350	210	30.9	1.7	0.85	7.2	3.6	8.2	4.1

[a] Results of SPLIN2 analysis reproduced from Table 4.6, p. 51 of the test report (Appendix G). Drum-mix process. Does not include any tests conducted during the processing of recycled asphalt paving.

[b] No paired mass run for this particle sizing run. Used the average total mass emission factor of all eightmass runs (30.9 lb/ton) to calculate size-specific emission factors.

[c] Average plant production rate during mass test run. Tons (2,000 lb) of asphalt concrete produced per hour.

[d] Pounds of particulate matter per short ton of asphalt concrete produced or kilograms of particulate matter per 10^6/g (Mg) of asphalt concrete produced.

TABLE 3-28. CALCULATED EMISSION FACTORS FOR REFERENCE 27 - BAGHOUSE OUTLET[a]

Data Rating: A

Test No.	Run No. source-run-quad	Total mass emission rate (lb/h)	Production rate (ton/h)[b]	Total mass emission factor (lb/ton)[c]	Ratio of total mass conc. to particle size train conc.	Size specific emission factors[c]					
						< 2.5 μm		< 10 μm		< 15 μm	
						(lb/ton)	(kg/Mg)	(lb/ton)	(kg/Mg)	(lb/ton)	(kg/Mg)
1	0-1-1(8)	11.5	164	0.07		0.008	0.004	0.028	0.014	0.03	0.015
	0-1-2[d]	12.7	226	0.056		0.004	0.002	0.011	0.006	0.012	0.006
	0-1-3[d]	16.6	216	0.077		0.007	0.004	0.019	0.010	0.021	0.011
	0-1-4	9.6	237	0.041		0.004	0.002	0.013	0.007	0.013	0.007
	Average	12.6	211	0.061	0.59	0.006	0.003	0.018	0.009	0.019	0.010
2	0-2-1	9.6	174	0.055		0.011	0.006	0.028	0.014	0.031	0.016
	0-2-2	7.3	216	0.034		0.004	0.002	0.012	0.006	0.012	0.006
	0-2-3	24.7	195	0.127		0.011	0.006	0.035	0.018	0.044	0.022
	0-2-4	10.0	178	0.056		0.004	0.002	0.016	0.006	0.021	0.011
	Average	12.9	191	0.068	0.65	0.008	0.004	0.023	0.012	0.027	0.014
	Total average	12.8	201	0.065		0.007	0.004	0.021	0.011	0.023	0.012

[a] Results of SPLIN2 analysis reproduced from Table 4.7, p. 52 of the test report (Appendix G). Drum mix process.

[b] Average plant production rate during test run. Tons (2,000 lb) of asphalt concrete produced per hour.

[c] Pounds of particulate matter per short ton of asphalt concrete produced or kilograms of particulate matter per 10^6 g (Mg) of asphalt concrete produced.

[d] Test conducted during the processing of ~ 30% recycled asphalt paving.

TABLE 3-29. EMISSION FACTORS FOR CONDENSABLE ORGANICS - REFERENCE 27[a]

Data Rating: A

Run No.[c]	Date	Ratio of total stack flow rate to sampler flow rate	Total emissions (lb/hr)	Average production rate[b] (tons/hr)	Total mass emission factor (lb/ton)	% Condensable	Size-specific emission factor > 15 μm (lb/ton)	> 15 μm (kg/Mg)	2.5-15 μm (lb/ton)	2.5-15 μm (kg/Mg)	< 2.5 μm (lb/ton)	< 2.5 μm (kg/Mg)
1 IP	10/7/81	62,200	0.838	339	0.00247	-	0.0016	0.0008	0.00043	0.00022	0.00044	0.00022
1 SDSS		71,500	-		-		-		-		-	
2 IP	10/8/81	70,300	2.27	290	0.0078	43.7	0.0069	0.0035	0.00035	0.00018	0.00055	0.00028
2 SDSS		85,400	3.47		0.012		0.0055	0.0028	0.00075	0.00038	0.0057	0.0029
3 IP	10/9/81	71,100	4.70	322	0.0155	35.6	0.013	0.0065	0.0016	0.00080	0.00060	0.0003
3 SDSS		81,500	5.54		0.0172		0.0087	0.0044	0.0019	0.00095	0.0066	0.0033
4 IP	10/9/81	80,200	1.65	252	0.00655	57.2	0.0045	0.0023	0.00098	0.00049	0.0011	0.00055
4 SDSS		84,800	5.10		0.0202		0.0066	0.0033	0.00098	0.00049	0.013	0.0065

[a] Reproduced from Table 5.5, p. 82 of Reference 27 (Appendix G). Drum-mix process with split feed. All tests conducted during the processing of ~ 30% recycled asphalt paving.

[b] Average production rate for test period except for Run 2 where the daily average was used to calculate the emission factor. Short tons of asphalt concrete produced per hour.

[c] IP - Sampling train consisting of a dual cyclone plus standard back-up filter.
SDSS - Sampling train consisting of a dual cyclone followed by an atmospheric dilution chamber and back-up filter.

Another notation which should be made is in regard to the information derived from Reference 3. In this case, the particle size data for the uncontrolled emissions from the dryer were expressed in terms of their settling velocity rather than particle size. Calculations were, therefore, made to convert the data from the applicable settling velocity to Stoke's diameter using Equation 5. A summary of such a determination is provided in Table 3-20 with the calculations themselves included in Appendix J.

3.5.3 Development of Candidate Emission Factors and AP-42 Background

The ideal situation would be to average a large number of A-rated data sets to obtain a single-valued emission factor which would represent a broad cross section of the asphalt paving industry. As outlined in the above discussion, such data were not available for this particulate study. In the case of batch and continuous plants, there were no A-rated data contained in the information collected and only three B-rated data sets consisting of a total of four individual test runs at three different facilities. For drum-mix plants, only one A-rated test at a single facility is included in the entire data base. This lack of high quality data makes the development of appropriate size-specific emission factors for asphalt concrete plants very difficult.

According to the OAQPS guidelines, A- and B-rated data should not be combined with C- or D-rated data to develop emission factors for a particular source. However, in the case of conventional plants it was found necessary to combine a small amount of B-rated data with a substantial C- and D-rated data base in order to improve the overall quality of the emission factors. This was deemed appropriate since the total number of B-rated tests was so low that the inclusion of the C- and D-data would significantly enhance the overall applicability of the emission factor to a larger number of facilities utilizing a greater diversity of raw material.

To derive each emission factor, the information contained in Tables 3-16 through 3-29 was tabulated according to the type of process and control equipment, and the arithmetic mean and standard deviation were calculated wherever possible for each particle size increment. The arithmetic mean was calculated from the data in each column according to the relationship:

$$\bar{x} = \frac{1}{n} \sum_{i=1}^{n} x_i \qquad (8)$$

where: $\bar{x}$ = arithmetic mean

n = number of measurements

x_i = individual measurements

The standard deviation was calculated according to the relationship:

$$\sigma = \left[\frac{\Sigma x_i^2 - \frac{(\Sigma x_i)^2}{n}}{n-1} \right]^{1/2} \quad (9)$$

where: σ = standard deviation with x_i and n as defined in Equation (8)

The geometric mean and standard deviation were also calculated, with the standard geometric deviation being indicative of the overall variance in the data. The geometric mean was calculated from the data in each column according to the relationship:

$$\bar{x}_g = \exp \frac{1}{n} \sum_{i=1}^{n} \ln x_i \quad (10)$$

where: $\bar{x}_g$ = geometric mean with x_i and n as defined in Equation (8)

The standard geometric deviation was calculated according to the relationship:

$$\sigma_g = \exp \left[\sum_{i=1}^{n} \frac{(\ln x_i - \ln \bar{x})^2}{n-1} \right]^{1/2} \quad (11)$$

where: σ_g = standard geometric deviation with x_i and n as defined in Equation (8)

Rather than utilizing the emission factors actually derived from each study, the candidate emission factor for each size increment was obtained by applying the particle size distribution from the various data sets to the existing AP-42 emission factor (if any). This approach was used to take advantage of the significant data base which already exists for the total mass emissions from asphalt concrete plants. It was felt that this was superior to utilizing emission factors based on limited data of sometimes marginal quality and would produce emission factors much more representative of the total industry. The results of this analysis are shown in Tables 3-30 through 3-35.

Since both the batch and continuous process use similar mechanical equipment (and thus would have similar emissions), data for these plants were combined under the generic category of "conventional asphalt plants," and emission factors were calculated for each type of control equipment for which data were available.

TABLE 3-30. CANDIDATE PARTICULATE EMISSION FACTORS FOR UNCONTROLLED CONVENTIONAL ASPHALT PLANTS

Emission Factor Rating: D[a]

Reference No.	Test ID No.	Summary data table No.[b]	Data quality rating	Cumulative mass equal to or less than stated size (%)[c] 2.5 µmA	5.0 µmA	10.0 µmA	15.0 µmA	20.0 µmA	Cumulative particulate emission factor less than stated size (kg/Mg)[d] 2.5 µmA	5.0 µmA	10.0 µmA	15.0 µmA	20.0 µmA	Total mass emission factor (kg/Mg)
1	C-426[e]	3-19	D	0.803	4.56	13.7	20.4	25.2	0.181	1.03	3.08	4.59	5.67	22.5
3	A4	3-21	C	0.774	4.29	13.9	21.6	26.3	0.174	0.965	3.13	4.86	5.92	22.5
3	D1	3-21	C	0.0803	1.67	10.4	16.9	20.9	0.0181	0.376	2.34	3.80	4.70	22.5
3	H2	3-21	C	0.0576	1.78	13.3	21.9	25.7	0.013	0.401	2.99	4.93	5.78	22.5
3	I2	3-21	C	3.03	6.86	12.6	16.1	21.5	0.682	1.54	2.84	3.62	4.84	22.5
3	J3	3-21	C	0.0502	2.34	22.0	38.0	45.7	0.0113	0.527	4.95	8.55	10.3	22.5
3	D2	3-21	C	2.68	7.39	20.2	36.7	52.2	0.603	1.66	4.55	8.26	11.8	22.5
3	C1	3-21	C	0.138	1.81	10.4	19.7	26.3	0.0311	0.407	2.34	4.43	5.92	22.5
3	C2	3-21	C	0.0259	1.24	12.4	22.8	28.8	0.00583	0.279	2.79	5.13	6.48	22.5
3	B3	3-21	C	0.197	1.40	6.02	11.1	15.6	0.0443	0.315	1.35	2.50	3.51	22.5
3	D4	3-21	C	1.25	6.33	21.8	37.7	48.9	0.281	1.42	4.91	8.48	11.0	22.5
3	F3	3-21	C	0.219	3.07	15.8	25.6	32.1	0.0493	0.691	3.56	5.76	7.22	22.5
3	G2	3-21	C	0.0633	1.54	14.0	32.3	44.9	0.0142	0.347	3.15	7.27	10.1	22.5
3	G1	3-21	C	0.00672	0.647	11.0	25.9	32.5	0.00151	0.146	2.48	5.83	7.31	22.5
3	B1	3-21	C	0.956	2.13	4.38	6.47	8.06	0.215	0.479	0.986	1.46	1.81	22.5
3	F2	3-21	C	2.96	8.76	20.5	30.1	38.0	0.666	1.97	4.61	6.77	8.55	22.5
12	C-537[f]	3-25	D	0.726	2.94	8.91	14.9	20.0	0.163	0.662	2.00	3.35	4.50	22.5
Arithmetic Mean ($\bar{x}$)				0.825	3.46	13.6	23.4	30.1	0.185	0.777	3.06	5.27	6.79	
Geometric Mean (x_g)				0.269	2.71	12.6	21.4	27.5	0.0604	0.610	2.83	4.82	6.20	
Standard Deviation (σ)				1.06	2.48	5.17	9.23	12.3	0.238	0.556	1.17	2.08	2.77	
Std. Geometric Dev. (σ_g)				6.13	2.07	1.54	1.59	1.59	6.13	2.07	1.55	1.59	1.60	

[a] See Section 3.5.4 for rationale.

[b] Table included in this report from which the reduced data was taken.

[c] Aerodynamic diameter.

[d] Based on a total mass emission factor of 22.5 kg/Mg per Table 8.1-3 of AP-42. Results of calculations rounded to three significant figures.

[e] Includes dryer emissions only.

[f] Includes emissions from dryer and scavenger system (vent line).

TABLE 3-31. CANDIDATE EMISSION FACTORS FOR CYCLONE DUST COLLECTORS IN CONVENTIONAL ASPHALT PLANTS

Emission Factor Rating: D[a]

Reference No.	Test ID No.	Summary data table No.[b]	Data quality rating	Cumulative mass equal to or less than stated size (%)[c] 2.5 µmA	5.0 µmA	10.0 µmA	15.0 µmA	20.0 µmA	Cumulative particulate emission factor equal to or less than stated size (kg/Mg)[d] 2.5 µmA	5.0 µmA	10.0 µmA	15.0 µmA	20.0 µmA	Total mass emission factor (kg/Mg)
1	C-426[e,f]	3-19	D	0.833	2.93	6.92	9.96	12.6	0.00708	0.0249	0.0588	0.0847	0.107	0.85
1	C-393[f]	3-18	D	0.0112	0.0449	2.80	13.9	30.8	$9.52(10)^{-7}$	$3.82(10)^{-4}$	0.0238	0.118	0.262	0.85
3	A4	3-22	C	5.00	9.60	16.7	22.1	26.5	0.0425	0.0816	0.142	0.188	0.225	0.85
3	D1	3-22	C	2.38	6.02	12.4	17.3	21.0	0.0202	0.0512	0.105	0.147	0.178	0.85
3	H2	3-22	C	7.45	11.8	17.9	22.5	26.2	0.0633	0.100	0.152	0.191	0.223	0.85
3	I2	3-22	C	0.397	2.23	8.52	15.6	22.2	0.00337	0.0190	0.0724	0.133	0.188	0.85
3	I3	3-22	C	7.13	15.7	29.2	39.1	46.4	0.0606	0.133	0.247	0.332	0.394	0.85
3	D2	3-22	C	1.55	7.40	23.5	38.2	49.6	0.0132	0.0629	0.200	0.325	0.422	0.85
3	C1	3-22	C	2.68	6.60	14.1	20.7	26.3	0.0228	0.0561	0.120	0.176	0.224	0.85
3	C2	3-22	C	5.31	10.4	18.5	24.7	29.7	0.0451	0.0884	0.157	0.210	0.252	0.85
3	B3	3-22	C	0.622	2.29	6.74	11.5	16.0	0.00529	0.0195	0.0573	0.0978	0.136	0.85
3	D4	3-22	C	4.48	12.5	27.6	39.3	48.1	0.0381	0.106	0.235	0.334	0.409	0.85
3	F3	3-22	C	3.85	9.16	18.6	26.2	32.3	0.0327	0.0779	0.158	0.223	0.275	0.85
3	G2	3-22	C	2.48	8.63	22.5	34.6	44.2	0.0211	0.0734	0.191	0.294	0.376	0.85
3	G1	3-22	C	9.74	14.6	22.0	27.9	33.0	0.0828	0.124	0.187	0.237	0.281	0.85
3	B1	3-22	C	1.74	3.02	5.04	6.67	8.07	0.0148	0.0257	0.0428	0.0567	0.0686	0.85
3	F2	3-22	C	5.14	12.0	23.1	31.1	36.8	0.0437	0.102	0.196	0.264	0.313	0.85
8	Harrison[f]	3-24	B	20.7	45.5	62.6	68.1	71.7	0.176	0.387	0.532	0.579	0.609	0.85
8	Sloan[f]	3-23	B	17.6	35.6	54.7	61.7	65.9	0.150	0.303	0.465	0.524	0.560	0.85
12	C-537[f]	3-25	D	1.33	7.93	28.9	48.9	63.2	0.113	0.674	0.246	0.416	0.537	0.85
Arithmetic Mean ($\bar{x}$)				5.02	11.2	21.1	29.0	35.5	0.0478	0.125	0.179	0.247	0.302	
Geometric Mean (x_g)				2.44	6.60	16.5	24.7	31.1	0.0185	0.0629	0.140	0.210	0.264	
Standard Deviation (σ)				5.51	11.0	15.2	16.6	17.7	0.0488	0.159	0.129	0.141	0.150	
Std. Geometric Dev. (σ_g)				5.15	4.12	2.16	1.83	1.75	13.0	4.58	2.16	1.83	1.75	

[a] See Section 3.5.4 for rationale.

[b] Table included in this report from which the raw data was taken.

[c] Aerodynamic diameter.

[d] Based on a total mass emission factor of 0.85 kg/Mg per Table 8.1-3 of AP-42. Results of calculations rounded to three significant figures.

[e] Includes exhaust from a single cyclone and the scavenger system (vent line).

[f] Single cyclone collector.

TABLE 3-32. CANDIDATE PARTICULATE EMISSION FACTORS FOR CONVENTIONAL ASPHALT PALNTS CONTROLLED BY MULTIPLE CENTRIFUGAL SCRUBBERS

Emission Factor Rating: D

Reference No.	Test ID No.	Data quality rating	Summary data table No.[c]	Cumulative mass equal to or less than stated size (%)[a] 2.5 µmA	5.0 µmA	10.0 µmA	15.0 µmA	20.0 µmA	Cumulative particulate emission factor equal to or less than stated size (kg/Mg)[b] 2.5 µmA	5.0 µmA	10.0 µmA	15.0 µmA	20.0 µmA	Total mass emission factor (kg/Mg)
1	C-369	D	3-17	62.9	70.3	76.6	79.6	81.5	0.022	0.025	0.027	0.028	0.029	0.035
1	C-372A	D	3-17	57.1	68.3	78.0	82.6	85.2	0.020	0.024	0.027	0.029	0.030	0.035
1	C-372B	D	3-17	69.5	74.9	79.5	81.8	83.2	0.024	0.026	0.028	0.029	0.029	0.035
1	C-422(1)	D	3-17	56.4	63.1	69.5	72.9	75.1	0.020	0.022	0.024	0.026	0.026	0.035
8	Harrison	B	3-24	89.8	94.3	95.8	96.2	96.5	0.031	0.033	0.034	0.034	0.034	0.035
Arithmetic Mean ($\bar{x}$)			-	67.1	74.2	79.9	82.6	84.3	0.023	0.026	0.028	0.029	0.030	0.035
Geometric Mean (xg)				66.1	73.5	79.4	82.3	84.0	0.023	0.026	0.028	0.029	0.030	
Standard Deviation (σ)			-	13.7	12.0	9.69	8.50	7.80	0.005	0.004	0.004	0.003	0.003	-
Std. Geometric Dev. (σg)				1.21	1.16	1.12	1.11	1.09	1.20	1.16	1.13	1.10	1.10	

[a] Aerodynamic diameter.

[b] Based on a total mass emission factor of 0.035 kg/Mg per Table 8.1-3 of AP-42 for multiple centrifugal scrubbers. Results of calculations rounded to two significant figures.

[c] Table included in this report from which the raw data was obtained.

TABLE 3-33. CANDIDATE PARTICULATE EMISSION FACTORS FOR CONVENTIONAL ASPHALT PLANTS CONTROLLED BY GRAVITY SPRAY TOWERS[a]

Emission Factor Rating: D

Particle size (μmA)[b]	Cumulative mass % equal to or less than stated size	Cumlative emission factor equal to or less than stated size (kg/Mg)[c]
2.5	20.5	0.041
5.0	26.6	0.053
10.0	36.5	0.073
15.0	38.9	0.078
20.0	40.6	0.081
Total mass emission factor	-	0.20

[a] Based on data contained in Reference 8 for Sloan Construction Company (see Table 3-23). Data Rating: B.

[b] Aerodynamic diameter.

[c] Based on a total mass emission factor of 0.20 kg/Mg per Table 8.1-3 of AP-42 for spray towers. Results of calculations rounded to two significant figures.

TABLE 3-34. CANDIDATE PARTICULATE EMISSION FACTORS FOR CONVENTIONAL ASPHALT PLANTS CONTROLLED BY A BAGHOUSE COLLECTOR[a]

Emission Factor Rating: D

Particle size (μmA)[b]	Cumulative mass % equal to or less than stated size	Cumlative emission factor equal to or less than stated size (kg/Mg)[c]
2.5	33.2	0.003
5.0	35.8	0.004
10.0	40.4	0.004
15.0	46.8	0.005
20.0	53.9	0.005
Total mass emission factor	-	0.01

[a] Based on data contained in Reference 26 (see Table 3-26). Data Rating: B.

[b] Aerodynamic diameter.

[c] Based on a total mass emission factor of 0.01 kg/Mg per Table 8.1-3 of AP-42 for baghouses. Results of calculations rounded to one significant figure.

TABLE 3-35. CANDIDATE PARTICULATE EMISSION FACTORS FOR DRUM-MIX ASPHALT PLANTS CONTROLLED BY A BAGHOUSE COLLECTOR[a]

Emission Factor Rating: D

Particle size (μmA)[b]	Cumulative mass equal to or less than stated size (%)[c]		Cumulative particulate emission factors equal to or less than stated size			
			Uncontrolled[d]		Controlled[e]	
	Uncontrolled	Controlled[f]	kg/Mg	lb/ton	kg/Mg	lb/ton
2.5	5.5	11	0.14	0.27	$5.3\ (10)^{-4}$	$1.1\ (10)^{-3}$
10.0	23	32	0.57	1.1	$1.6\ (10)^{-3}$	$3.2\ (10)^{-3}$
15.0	27	35	0.65	1.3	$1.7\ (10)^{-3}$	$3.5\ (10)^{-3}$
Total mass emission factor			2.5	4.9	$4.9\ (10)^{-3}$	$9.8\ (10)^{-3}$
Condensable organics[g]					$3.9\ (10)^{-3}$	$7.7\ (10)^{-3}$

[a] Based on the data contained in Reference 27. Data Rating: A. Rounded to two significant figures.

[b] Aerodynamic diameter.

[c] Calculated directly from Tables 3-27 and 3-28 using the uncontrolled and controlled emission factors (see Appendix K).

[d] Based on an uncontrolled emission factor of 2.45 kg/Mg per Table 8.1-5 of AP-42 (see Appendix K).

[e] Calculated using an overall collection efficiency of 99.8% for a baghouse per the data contained in Tables 3-27 and 3-28 applied to an uncontrolled emission factor of 2.45 kg/Mg (see Appendix K).

[f] Includes data from two tests out of eight where ~ 30% recycled asphalt paving was being processed.

[g] Emission factor calculated from Table 5.4, p. 81 of Reference 27 (see Appendix K). Emissions determined at the outlet of the baghouse with the plant processing ~ 30% recycled asphalt paving.

A summary of the size-specific emission factors for conventional asphalt plants is shown in Table 3-36 and graphically in Figure 3-4 by drawing a smooth curve through the various data points.

In the case of drum-mix plants, there is no applicable factor published in AP-42 for the total mass emissions from plants controlled by a baghouse collector. To calculate the various size-specific emission factors contained in Table 3-35, the overall collection efficiency for the baghouse as determined during the testing program (99.8%) was applied to the uncontrolled emission factor (2.45 kg/Mg) published in AP-42 to obtain a controlled emission factor for total particulate (0.0049 kg/Mg). The percentage of the total mass in each particle size increment (< 2.5, < 10, and < 15 μmA, respectively) was then used to calculate each of the size-specific emission factors using the total mass emissions as determined above. The results of such a determination are also shown graphically in Figure 3-5. Copies of appropriate calculations are contained in Appendix K.

Table 3-35 also contains an emission factor for condensable organics as determined from Reference 27. This factor is based on data taken directly from the report with no further manipulations. Since the data base used to derive the total mass emission factor for drum-mix plants theoretically includes only measurements of the particulate matter contained in the exhaust of the drum mixer at stack temperature and pressure, it was deemed inappropriate to use the published factor for any determination of condensable organics.

3.5.4 Emission Factor Quality Rating

The quality of the average emission factors contained in Tables 3-30 through 3-35 was rated utilizing the following general criteria:[28]

- A - Excellent: Developed only from A-rated test data taken from many randomly chosen facilities in the industry population. The source category* is specific enough to minimize variability within the source category population.

- B - Above average: Developed only from A-rated test data from a reasonable number of facilities. Although no specific bias is evident, it is not clear if the facilities tested represent a random sample of the industries. As in the A-rating, the source category is specific enough to minimize variability within the source category population.

- C - Average: Developed only from A- and B-rated test data from a reasonable number of facilities. Although no specific bias is evident, it is not clear if the facilities tested represent a random sample of the industry. As in the A-rating, the source category is specific enough to minimize variability within the source category population.

* Source category: A category in the emission factor table for which an emission factor has been calculated (generally a single process).

TABLE 3-36. SUMMARY OF CANDIDATE EMISSION FACTORS FOR CONVENTIONAL ASPHALT PLANTS

Emission Factor Rating: D

Particle size (μmA)[a]	Cumulative mass equal to or less than stated size (%)					Cumulative particulate emission factor equal to or less than stated size									
	Uncontrolled[e]	Cyclone collectors[f]	Multiple centrifugal scrubbers[g]	Gravity spray towers[h]	Baghouse collector[i]	Uncontrolled[b]		Cyclone collectors[c]		Multiple centrifugal scrubbers[c]		Gravity spray towers[c]		Baghouse collector[d]	
						kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton
2.5 μmA	0.825	5.02	67.1	20.5	33.2	0.185	0.370	0.048	0.096	0.023	0.046	0.041	0.082	0.003	0.006
5.0 μmA	3.46	11.2	74.2	26.6	35.8	0.777	1.55	0.13	0.26	0.026	0.052	0.053	0.11	0.004	0.008
10.0 μmA	13.6	21.1	79.9	36.5	40.4	3.06	6.12	0.18	0.36	0.028	0.056	0.073	0.15	0.004	0.008
15.0 μmA	23.4	29.0	82.6	38.9	46.8	5.27	10.5	0.25	0.50	0.029	0.058	0.078	0.16	0.005	0.01
20.0 μmA	30.1	35.5	84.3	40.6	53.9	6.79	13.6	0.30	0.60	0.030	0.060	0.081	0.16	0.005	0.01
Total mass emission factor						22.5	45.0	0.85	1.7	0.035	0.070	0.20	0.40	0.01	0.02

[a] Aerodynamic diameter.

[b] Rounded to three significant figures. Unit weight of particulate matter per unit weight of asphalt concrete produced. 1 ton = 2,000 lb.

[c] Rounded to two significant figures. Unit weight of particulate matter per unit weight of asphalt concrete produced. 1 ton = 2,000 lb.

[d] Rounded to one significant figure. Unit weight of particulate matter per unit of weight of asphalt concrete produced. 1 ton = 2,000 lb.

[e] From Table 3-30.

[f] From Table 3-31.

[g] From Table 3-32.

[h] From Table 3-33.

[i] From Table 3-34.

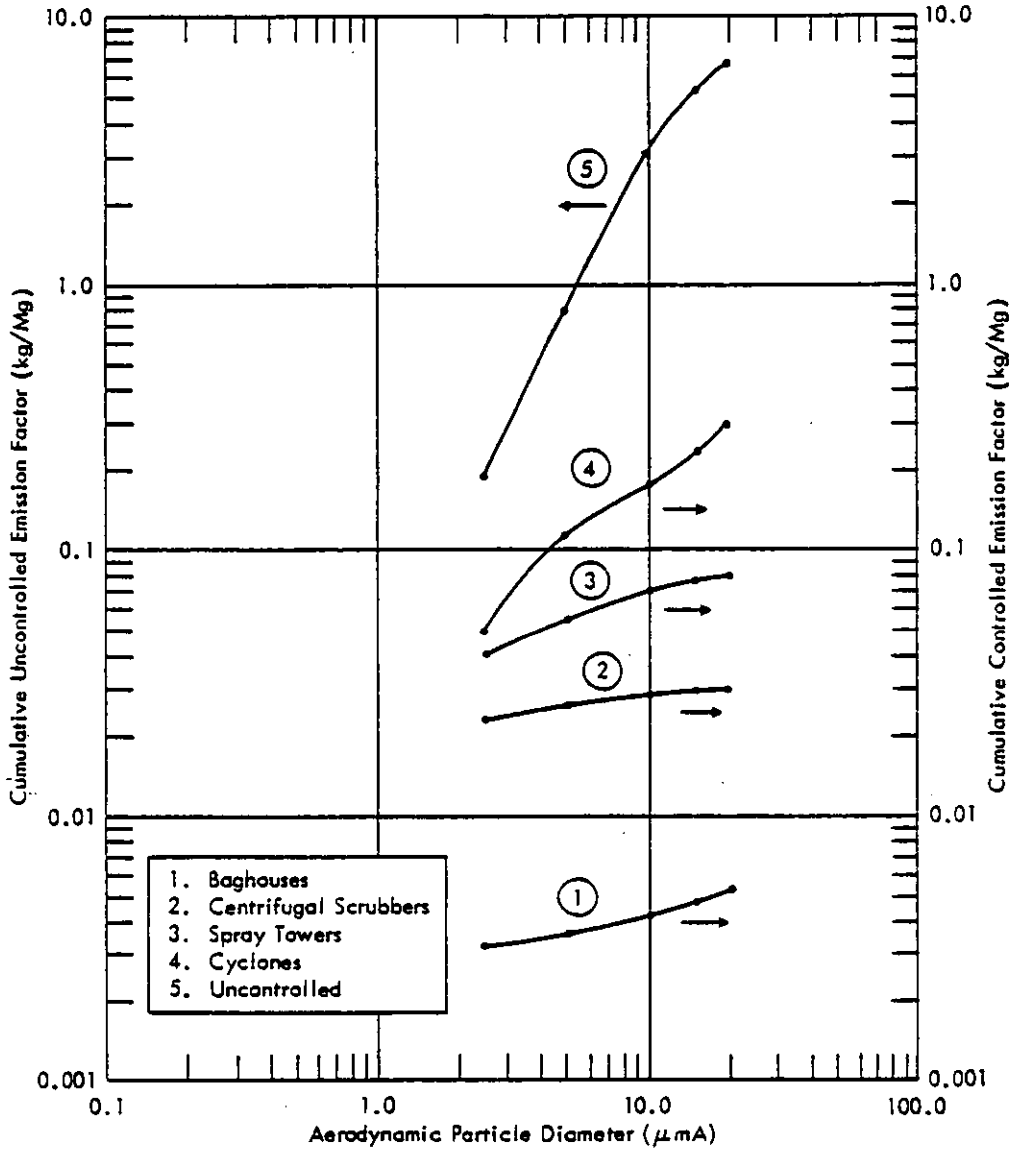

Figure 3-4. Size-specific emission factors for conventional asphalt plants.

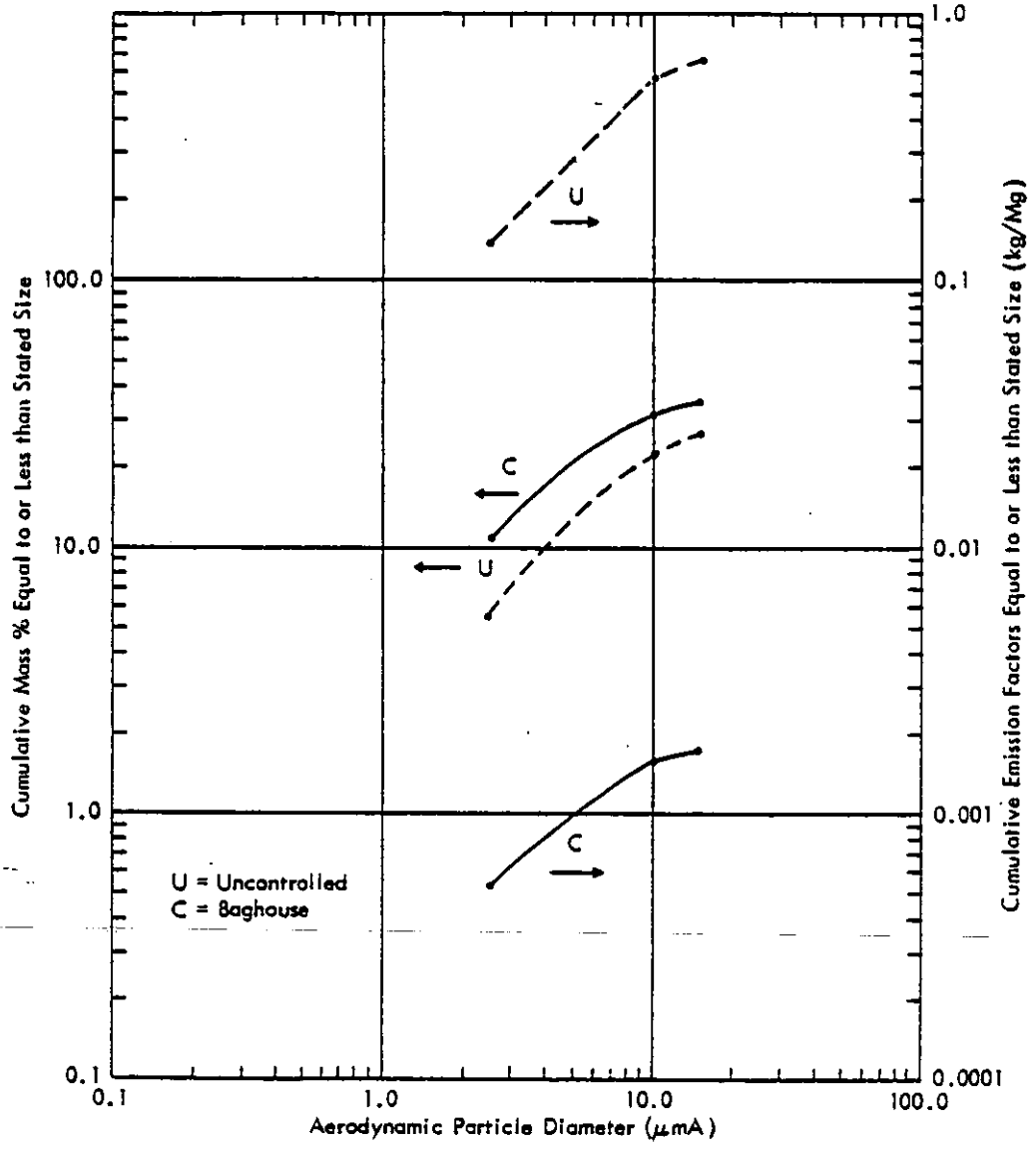

Figure 3-5. Particle size distribution and size-specific emission factors for drum-mix asphalt plants.

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

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

The use of the above criteria is somewhat subjective depending to a large extent on the individual reviewer.

In the case of both uncontrolled conventional plants and those equipped with cyclones, it was found necessary, in some instances, to apply lower quality (i.e., C- and D-rated) particle size data to a B-rated emission factor. Because of this large difference in data quality, it became difficult to ascertain what the overall rating of the resultant emission factor should be. Theoretically, a B emission factor has been calculated from only A-rated data sets which should not be combined with C or D particle size data. For this reason, a certain amount of good engineering judgment was employed to rate the quality of the various emission factors obtained. Even though the particle size data were sometimes only marginally acceptable, they were applied to a high quality emission factor. It would be expected, therefore, that something better than an order-of-magnitude estimate would be provided by such a procedure. For this reason, it was determined that a minimum of D would be the most appropriate rating for the resulting emission factors where large differences in data quality existed.

Because the overall quality of the emission factors determined in this study is generally low, it is helpful to define the range of process operating parameters and raw material characteristics to which the factors are most applicable. Table 3-37 provides information extracted from each reference document relative to the number of facilities tested compared to the total plant population in the United States, the number of tests conducted at each plant, the range of production rates tested, and the range of mineral filter (% < 200 mesh) content in the aggregate used in each study. From the available data, no good correlation could be derived which relates emissions to mineral filler content even though it is expected that such a relationship does actually exist. The information contained in Table 3-37 should give at least a general idea of what the process operating conditions were during testing and thus, where the above emission factors can be applied with at least a marginal degree of confidence.

TABLE 3-37. RANGE OF SOURCE OPERATING CHARACTERISTICS APPLICABLE TO THE CANDIDATE EMISSION FACTORS

Reference No.	No. and type of plants tested	No. of particle size tests/plant[a]	Percent of total population by process type	Range of production rates tested (TPH)[b]	Range of mineral filler content in wet aggregate (% wt)[c]
1	6-conventional	1	0.16	92 - 198	1.6 - 2.9
3	10-conventional	1 to 3	0.26	28 - 147	2 - 10
8	2-conventional	1 to 2	0.06	180 - 225	N/A
12	1-conventional	1	0.03	173	1.6
26	1-conventional	1	0.03	170	N/A
27	1-drum-mix	16	0.2%	138 - 372	1.5 - 5.4

[a] Either controlled or uncontrolled tests - not total number of runs.

[b] TPH - tons (2,000 lb) of asphalt concrete produced per hour.

[c] N/A - not available.

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*4. H. E. Friedrich, "Air Pollution Control Practices at Hot-Mix Asphalt Paving Batch Plants," JAPCA, 19(21):924-928, December 1969.

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* Indicates those documents found in the original literature search which contain particle size data (see page 27).

4.0 CHEMICAL CHARACTERIZATION

The only data available which chemically characterize the particulate emissions from asphalt concrete plants are those included in Reference 26 as described in Section 3.0 of this report. A compilation of these data for the emissions from the baghouse collector is shown in Table 4-1 (Appendix E, Table 4-59). No such data were collected for the plant tested under the IP program (Reference 27).

TABLE 4-1. CHEMICAL COMPOSITION OF THE PARTICULATE EMISSIONS FROM AN ASPHALT BATCH PLANT CONTROLLED BY A BAGHOUSE COLLECTOR[26]

Type of element or compound	Percent by weight	
	10-μm cyclone	Filter
WT % OF CUT	62.1	3.57
XRF ANALYSIS		
Arsenic	t	-
Barium	t	-
Calcium	2.4/0.3	10/3
Chromium	t	-
Iron	3.6/0.5	1/0.1
Potassium	1.5/0.5	-
Silver	t	-
(Sulfur)	(< 8)	(< 4)
Titanium	t	t
TOTAL[a]	8	11
Sulfates, H_2O sol[b] (sulfur, from SO_4^-)[c]	2 (t)	
Nitrate (H_2O sol)[b]	t	
TOTAL ANALYZED	10	11
BALANCE	90	89
	100%	100%

t = Detected in concentration of < 1%.

( ) = Not included in total--sulfur and sulfates are accounted for in sulfur XRF analysis.

[a] Analyzed by x-ray fluorescence.

[b] Analyzed by wet chemistry.

[c] Calculated from sulfates (sulfur=sulfate/3) to compare with sulfur from XRF.

5.0 PROPOSED AP-42 SECTION

The proposed revision to Section 8.1 of AP-42 is presented in the following pages. It should be noted that the terms "asphaltic cement" and "asphaltic concrete" are used in this section in place of "asphalt cement" and "asphalt concrete" as is more common in the industry. This was done to be consistent with the current version of Section 8.1 of AP-42. Such terminology has not been used elsewhere in this report.

8.1 ASPHALTIC CONCRETE PLANTS

8.1.1 General[1-2]

Asphaltic concrete paving is a mixture of well graded, high quality aggregate and liquid asphaltic cement which is heated and mixed in measured quantities to produce bituminous pavement material. Aggregate constitutes over 92 percent by weight of the total mixture. Aside from the amount and grade of asphalt used, mix characteristics are determined by the relative amounts and types of aggregate used. A certain percentage of fine aggregate (% < 74 μm in physical diameter) is required for the production of good quality asphaltic concrete.

Hot mix asphalt paving can be manufactured by batch mix, continuous mix or drum mix process. Of these various processes, batch mix plants are currently predominant. However, most new installations or replacements to existing equipment are of the drum mix type. In 1980, 78 percent of the total plants were of the conventional batch type, with 7 percent being continuous mix facilities and 15 percent drum mix plants. Any of these plants can be either permanent installations or portable.

Conventional Plants - Conventional plants produce finished asphaltic concrete through either batch (Figure 8.1-1) or continuous (Figure 8.1-2) mixing operations. Raw aggregate is normally stockpiled near the plant at a location where the bulk moisture content will stabilize to between 3 and 5 weight percent.

As processing for either type of operation begins, the aggregate is hauled from the storage piles and is placed in the appropriate hoppers of the cold feed unit. The material is metered from the hoppers onto a conveyor belt and is transported into a gas or oil fired rotary dryer. Because a substantial portion of the heat is transferred by radiation, dryers are equipped with flights designed to tumble the aggregate to promote drying.

As it leaves the dryer, the hot material drops into a bucket elevator and is transferred to a set of vibrating screens and classified into as many as four different grades (sizes). The classified material then enters the mixing operation.

In a batch plant, the classified aggregate drops into four large bins according to size. The operator controls the aggregate size distribution by opening various bins over a weigh hopper until the desired mix and weight are obtained. This material is dropped into a pug mill (mixer) and is mixed dry for about 15 seconds. The asphalt, a solid at ambient temperature, is pumped from a heated storage tank, weighed and injected into the mixer. Then the hot mix is dropped into a truck and is hauled to the job site.

In a continuous plant, the dried and classified aggregate drops into a set of small bins which collect the aggregate and meter it through a set of feeder conveyors to another bucket elevator and into the mixer. Asphalt is metered through the inlet end of the mixer, and retention time is

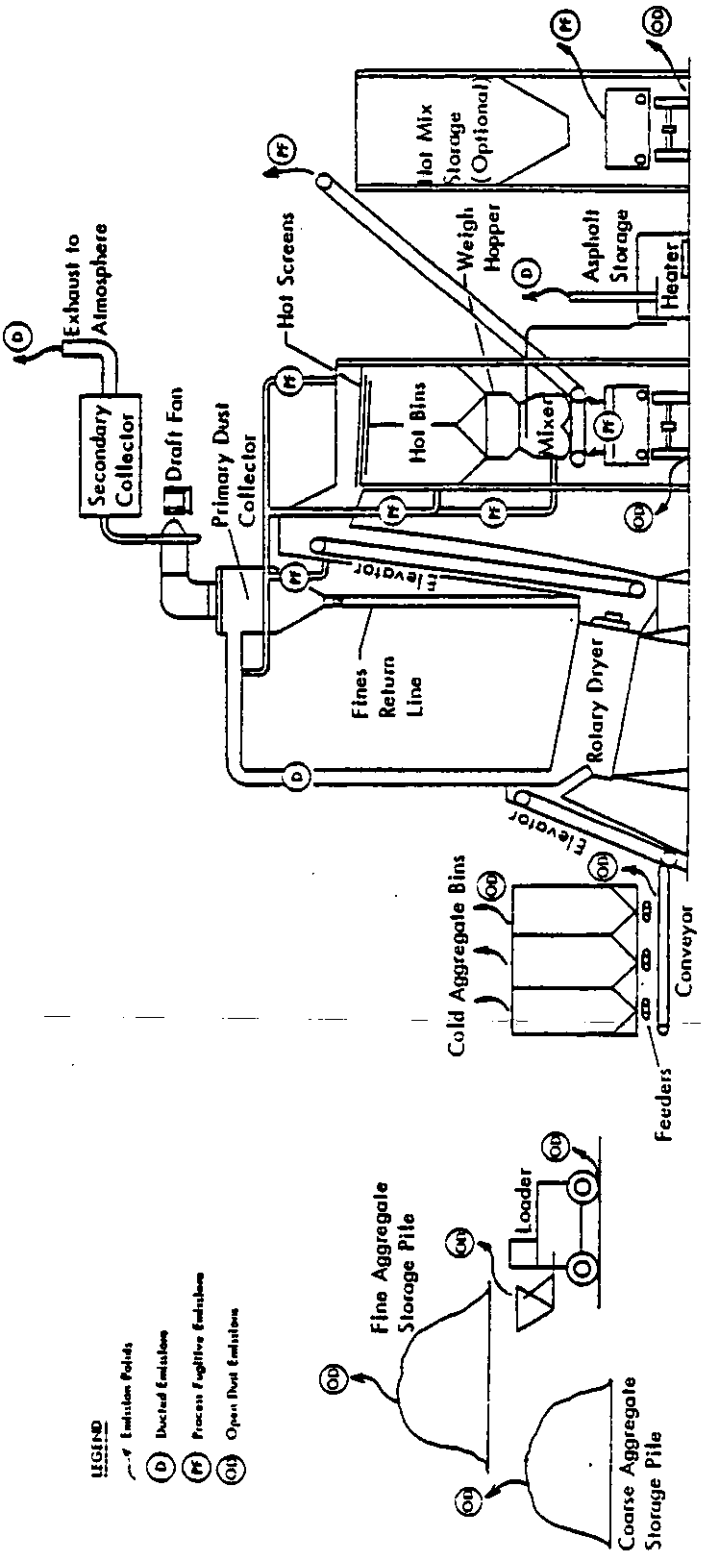

Figure 8.1-1. General process flow diagram for batch mix asphalt paving plants.

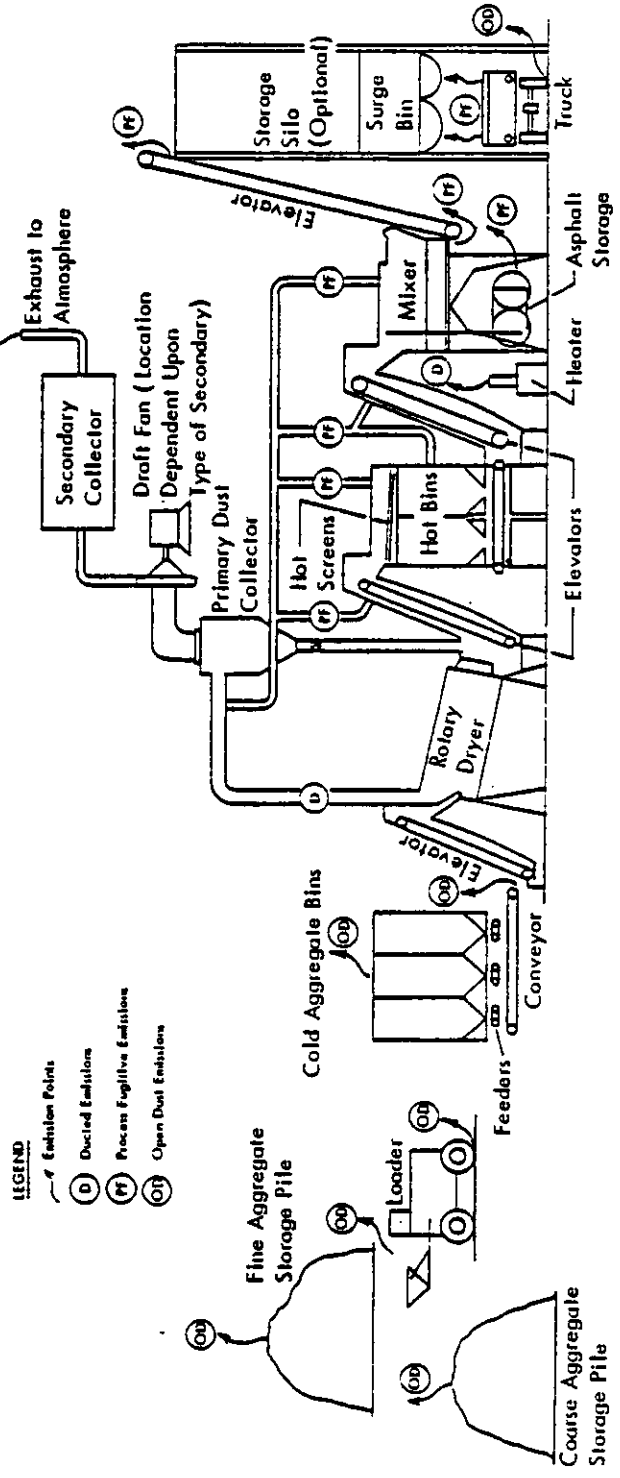

Figure 8.1-2. General process flow diagram for continuous mix asphalt paving plants.

controlled by an adjustable dam at the opposite end. The hot mix flows out of the mixer into a surge hopper, from which trucks are loaded.

Drum Mix Plants - The drum mix process simplifies the conventional process by using proportioning feed controls in place of hot aggregate storage bins, vibrating screens and the mixer. Aggregate is introduced near the burner end of the revolving drum mixer, and the asphalt is injected midway along the drum. A variable flow asphalt pump is linked electronically to the aggregate belt scales to control mix specifications. The hot mix is discharged from the revolving drum mixer into surge bins or storage silos. Figure 8.1-3 is a diagram of the drum mix process.

Drum mix plants generally use parallel flow design for hot burner gases and aggregate flow. Parallel flow has the advantage of giving the mixture a longer time to coat and to collect dust in the mix, thereby reducing particulate emissions. The amount of particulate generated within the dryer in this process is usually lower than that generated within conventional dryers, but because asphalt is heated to high temperatures for a long period of time, organic emissions (gaseous and liquid aerosol) are greater than in conventional plants.

Recycle Processes - In recent years, recycling of old asphalt paving has been initiated in the asphaltic concrete industry. Recycling significantly reduces the amount of new (virgin) rock and asphaltic cement needed to repave an existing road. The various recycling techniques include both cold and hot methods, with the hot processing conducted at a central plant.

In recycling, old asphalt pavement is broken up at a job site and is removed from the road base. This material is then transported to the plant, crushed and screened to the appropriate size for further processing. The paving material is then heated and mixed with new aggregate (if applicable), to which the proper amount of new asphaltic cement is added to produce a grade of hot asphalt paving suitable for laying.

There are three methods which can be used to heat recycled asphalt paving before the addition of the asphaltic cement: direct flame heating, indirect flame heating, and superheated aggregate.

Direct flame heating is typically performed with a drum mixer, wherein all materials are simultaneously mixed in the revolving drum. The first experimental attempts at recycling used a standard drum mix plant and introduced the recycled paving and virgin aggregate concurrently at the burner end of the drum. Continuing problems with excessive blue smoke emissions led to several process modifications, such as the addition of heat shields and the use of split feeds.

One method of recycling involves a drum mixer with a heat dispersion shield. The heat shield is installed around the burner, and additional cooling air is provided to reduce the hot gases to a temperature below 430 to 650°C (800 to 1200°F), thus decreasing the amount of blue smoke. Although now considered obsolete, a drum within a drum design has also been successfully

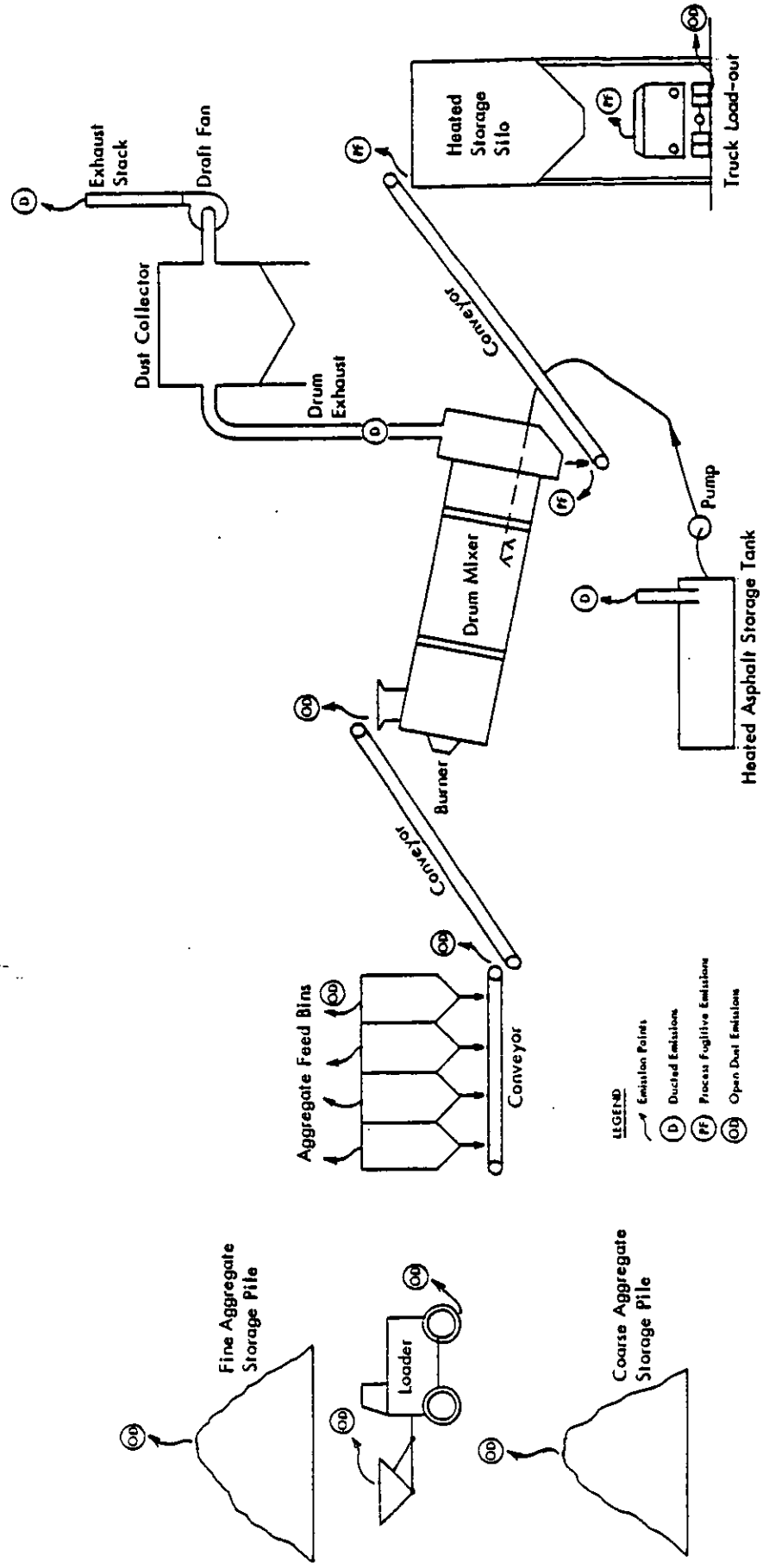

Figure 8.1-3. General process flow diagram for drum mix asphalt paving plants.

used for recycling. Reclaimed material is introduced into the outer drum through a separate charging chute while virgin material is introduced into the inner drum.

Split feed drum mixers were first used for recycling in 1976 and are now the most popular design. At about the midpoint of the drum, the recycled bituminous material is introduced by a split feed arrangement and is heated by both the hot gases and heat transfer from the superheated virgin aggregate. Another type of direct flame method involves the use of a slinger conveyor to throw recycled material into the center of the drum mixer from the discharge end. In this process, the recycled material enters the drum along an arc, landing approximately at the asphalt injection point.

Indirect flame heating has been performed with special drum mixers equipped with heat exchanger tubes. These tubes prevent the mixture of virgin aggregate and recycled paving from coming into direct contact with the flame and the associated high temperatures. Superheated aggregate can also be used to heat recycled bituminous material.

In conventional plants, recycled paving can be introduced either into the pug mill or at the discharge end of the dryer, after which the temperature of the material is raised by heat from the virgin aggregate. The proper amount of new asphaltic cement is then added to the virgin aggregate/recycle paving mixture to produce high grade asphaltic concrete.

Tandem drum mixers can also be used to heat the recycle material. The first drum or aggregate dryer is used to superheat the virgin aggregate, and a second drum or dryer either heats recycled paving only or mixes and heats a combination of virgin and recycled material. Sufficient heat remains in the exhaust gas from the first dryer to heat the second unit also.

8.1.2 Emissions and Controls

Emission points at batch, continuous and drum mix asphalt plants discussed below refer to Figures 8.1-1, 8.1-2 and 8.1-3, respectively.

Conventional Plants - As with most facilities in the mineral products industry, conventional asphaltic concrete plants have two major categories of emissions, those which are vented to the atmosphere through some type of stack, vent or pipe (ducted sources), and those which are not confined to ducts and vents but are emitted directly from the source to the ambient air (fugitive sources). Ducted emissions are usually collected and transported by an industrial ventilation system with one or more fans or air movers, eventually to be emitted to the atmosphere through some type of stack. Fugitive emissions result from process sources, which consist of a combination of gaseous pollutants and particulate matter, or open dust sources.

The most significant source of ducted emissions from conventional asphaltic concrete plants is the rotary dryer. The amount of aggregate dust carried out of the dryer by the moving gas stream depends upon a number of factors, including the gas velocity in the drum, the particle size distribution

of the aggregate, and the specific gravity and aerodynamic characteristics of the particles. Dryer emissions also contain the fuel combustion products of the burner.

There may also be some ducted emissions from the heated asphalt storage tanks. These may consist of combustion products from the tank heater.

The major source of process fugitives in asphalt plants is enclosures over the hot side conveying, classifying and mixing equipment which are vented into the primary dust collector along with the dryer gas. These vents and enclosures are commonly called a "fugitive air" or "scavenger" system. The scavenger system may or may not have its own separate air mover device, depending on the particular facility. The emissions captured and transported by the scavenger system are mostly aggregate dust, but they may also contain gaseous volatile organic compounds (VOC) and a fine aerosol of condensed liquid particles. This liquid aerosol is created by the condensation of gas into particles during cooling of organic vapors volatilized from the asphaltic cement in the pug mill. The amount of liquid aerosol produced depends to a large extent on the temperature of the asphaltic cement and aggregate entering the pug mill. Organic vapor and its associated aerosol are also emitted directly to the atmosphere as process fugitives during truck loadout, from the bed of the truck itself during transport to the job site, and from the asphalt storage tank, which also may contain small amounts of polycyclic compounds.

The choice of applicable control equipment for the drier exhaust and vent line ranges from dry mechanical collectors to scrubbers and fabric collectors. Attempts to apply electrostatic precipitators have met with little success. Practically all plants use primary dust collection equipment like large diameter cyclones, skimmers or settling chambers. These chambers are often used as classifiers to return collected material to the hot elevator and to combine it with the drier aggregate. Because of high pollutant levels, the primary collector effluent is ducted to a secondary collection device. Table 8.1-1 presents total particulate emission factors for conventional asphaltic concrete plants, with the factors based on the type of control technology employed. Size specific emission factors for conventional asphalt plants, also based on the control of technology used, are shown in Table 8.1-2 and Figure 8.1-4. Interpolations of size data other than those shown in Figure 8.1-4 can be made from the curves provided.

There are also a number of open dust sources associated with conventional asphalt plants. These include vehicle traffic generating fugitive dust on paved and unpaved roads, handling aggregate material, and similar operations. The number and type of fugitive emission sources associated with a particular plant depend on whether the equipment is portable or stationary and whether it is located adjacent to a gravel pit or quarry. Fugitive dust may range from 0.1 micrometers to more than 300 micrometers in diameter. On the average, 5 percent of cold aggregate feed is less than 74 micrometers (minus 200 mesh). Dust that may escape collection before primary control generally consists of particulate having 50 to 70 percent of the total mass being less than 74 micrometers. Uncontrolled particulate emission factors for various types of fugitive sources in conventional asphaltic concrete plants can be found in Section 11.2.3 of this document.

TABLE 8.1-1. EMISSION FACTORS FOR TOTAL PARTICULATE FROM CONVENTIONAL ASPHALTIC CONCRETE PLANTS[a]

Type of control	Emission factor	
	kg/Mg	lb/ton
Uncontrolled[b,c]	22.5	45.0
Precleaner[c]	7.5	15.0
High efficiency cyclone	0.85	1.7
Spray tower	0.20	0.4
Baffle spray tower	0.15	0.3
Multiple centrifugal scrubber[d]	0.035	0.07
Orifice scrubber	0.02	0.04
Venturi scrubber[e]	0.02	0.04
Baghouse[f]	0.01	0.02

[a]References 1-2, 5-10, 14-16. Expressed in terms of emissions per unit weight of asphaltic concrete produced. Includes both batch mix and continuous mix processes.

[b]Almost all plants have at least a precleaner following the rotary drier.

[c]Reference 16. These factors differ from those given in Table 8.1-6 because they are for uncontrolled emissions and are from an earlier survey.

[d]Reference 15. Range of values = 0.004 - 0.0690 kg/Mg. Average from a properly designed, installed, operated and maintained scrubber, based on a study to develop New Source Performance Standards.

[e]References 14-15. Range of values = 0.013 - 0.0690 kg/Mg.

[f]References 14-15. Emissions from a properly designed, installed, operated and maintained baghouse, based on a study to develop New Source Performance Standards. Range of values = 0.008 - 0.018 kg/Mg.

TABLE 8.1-2. SUMMARY OF SIZE SPECIFIC EMISSION FACTORS FOR CONVENTIONAL ASPHALT PLANTS[a]

EMISSION FACTOR RATING: D

Particle size[b] (μmA)	Cumulative mass ≤ stated size (%)					Cumulative particulate emission factor ≤ stated size[c]									
						Uncontrolled		Cyclone collectors		Multiple centrifugal scrubbers		Gravity spray towers		Baghouse collector[d]	
	Uncontrolled	Cyclone collectors	Multiple centrifugal scrubbers	Gravity spray towers	Baghouse collector	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton
2.5 μmA	0.83	5.0	67	21	33	0.19	0.37	0.05[d]	0.10[d]	0.023	0.046	0.041	0.082	0.003	0.006
5.0 μmA	3.5	11	74	27	36	0.78	1.6	0.13	0.26	0.026	0.052	0.053	0.11	0.004	0.008
10.0 μmA	14	21	80	37	40	3.1	6.1	0.18	0.36	0.028	0.056	0.073	0.15	0.004	0.008
15.0 μmA	23	29	83	39	47	5.3	11	0.25	0.50	0.029	0.058	0.078	0.16	0.005	0.010
20.0 μmA	30	36	84	41	54	6.8	14	0.30	0.60	0.030	0.060	0.081	0.16	0.005	0.010
Total mass emission factor						23	45	0.85	1.7	0.035	0.070	0.20	0.40	0.01	0.02

[a] Reference 23, Table 3-36. Rounded to two significant figures.
[b] Aerodynamic diameter.
[c] Based on emission factors for total particulate shown in Table 8.1-1. Expressed in terms of emissions per unit weight of asphaltic concrete produced. Mg = 10^6 g; ton = 2,000 lb.
[d] Rounded to one significant figure.

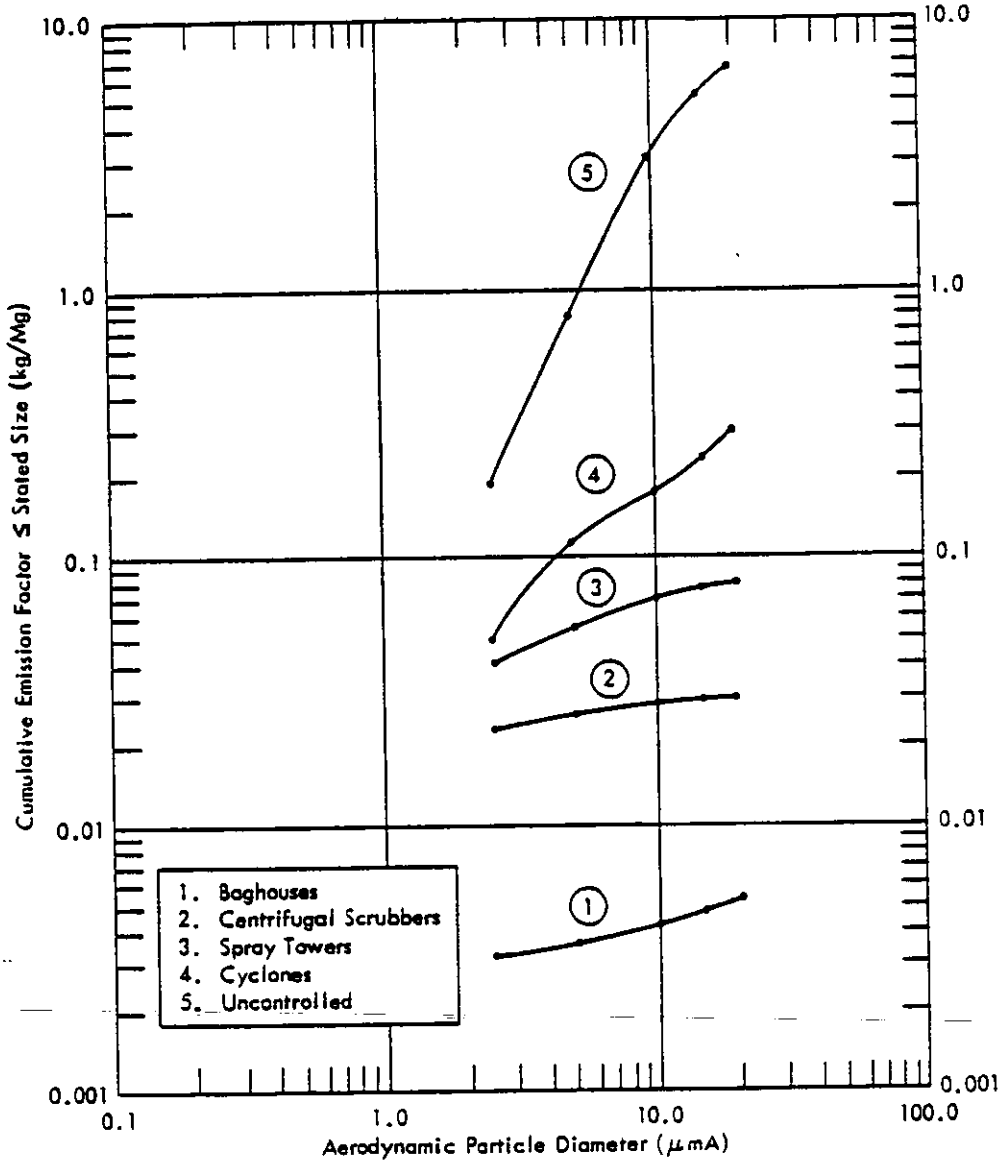

Figure 8.1-4. Size specific emission factors for conventional asphalt plants.

Drum Mix Plants - As with the other two asphaltic concrete production processes, the most significant ducted source of particulate emissions is the drum mixer itself. Emissions from the drum mixer consist of a gas stream with a substantial amount of particulate matter and lesser amounts of gaseous VOC of various species. The solid particulate generally consists of fine aggregate particles entrained in the flowing gas stream during the drying process. The organic compounds, on the other hand, result from heating and mixing of asphalt cement inside the drum, which volatilizes certain components of the asphalt. Once the VOC have sufficiently cooled, some condense to form the fine liquid aerosol (particulate) or "blue smoke" plume typical of drum mix asphalt plants.

A number of process modifications have been introduced in the newer plants to reduce or eliminate the blue smoke problem, including installation of flame shields, rearrangement of the flights inside the drum, adjustments in the asphalt injection point, and other design changes. Such modifications result in significant improvements in the elimination of blue smoke.

Emissions from the drum mix recycle process are similar to emissions from regular drum mix plants, except that there are more volatile organics because of the direct flame volatilization of petroleum derivatives contained in the old asphalt paving. Control of liquid organic emissions in the drum mix recycle process is through some type of process modification, as described above.

Table 8.1-3 provides total particulate emission factors for ducted emissions in drum mix asphaltic concrete plants, with available size specific emission factors shown in Table 8.1-4 and Figure 8.1-5.

TABLE 8.1-3. TOTAL PARTICULATE EMISSION FACTORS FOR DRUM MIX ASPHALTIC CONCRETE PLANTS[a]

EMISSION FACTOR RATING: B

Type of control	Emission factor kg/Mg	Emission factor lb/ton
Uncontrolled	2.45	4.9
Cyclone or multiclone	0.34	0.67
Low energy wet scrubber[b]	0.04	0.07
Venturi scrubber	0.02	0.04

[a]Reference 11. Expressed in terms of emissions per unit weight of asphaltic concrete produced. These factors differ from those for conventional asphaltic concrete plants because the aggregate contacts and is coated with asphalt early in the drum mix process.

[b]Either stack sprays, with water droplets injected into the exit stack, or a dynamic scrubber with a wet fan.

TABLE 8.1-4. PARTICLE SIZE DISTRIBUTION AND SIZE SPECIFIC EMISSION FACTORS FOR DRUM MIX ASPHALT PLANTS CONTROLLED BY A BAGHOUSE COLLECTOR[a]

EMISSION FACTOR RATING: D

Particle size (μmA)[b]	Cumulative mass ≤ stated size (%)		Cumulative particulate emission factors ≤ stated size[c]			
			Uncontrolled[d]		Controlled[e]	
	Uncontrolled	Controlled[f]	kg/Mg	lb/ton	10^{-3} kg/Mg	10^{-3} lb/ton
2.5	5.5	11	0.14	0.27	0.53	1.1
10.0	23	32	0.57	1.1	1.6	3.2
15.0	27	35	0.65	1.3	1.7	3.5
Total mass emission factor			2.5	4.9	4.9	9.8
Condensable organics[g]					3.9	7.7

[a]Reference 23, Table 3-35. Rounded to two significant figures.
[b]Aerodynamic diameter.
[c]Expressed in terms of emissions per unit weight of asphaltic concrete produced. Not generally applicable to recycle processes.
[d]Based on an uncontrolled emission factor of 2.45 kg/Mg (see Table 8.1-3).
[e]Reference 23. Calculated using an overall collection efficiency of 99.8% for a baghouse applied to an uncontrolled emission factor of 2.45 kg/Mg.
[f]Includes data from two out of eight tests where ~ 30% recycled asphalt paving was processed using a split feed process.
[g]Determined at outlet of a baghouse collector while plant was operating with ~ 30% recycled asphalt paving. Factors are applicable only to a direct flame heating process with a split feed.

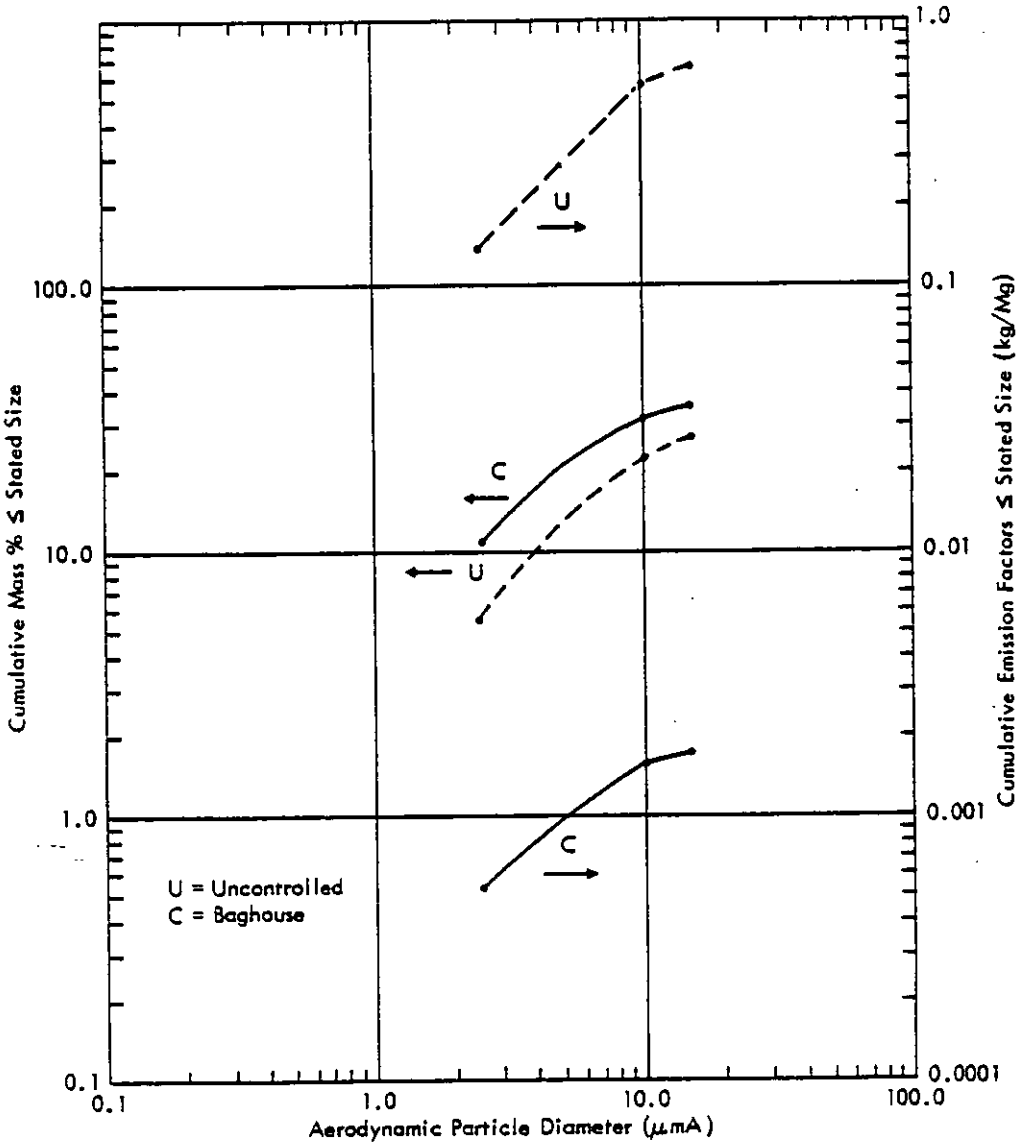

Figure 8.1-5. Particle size distribution and size specific emission factors for drum mix asphaltic concrete plants.

Interpolations of the data shown in Figure 8.1-5 to particle sizes other than those indicated can be made from the curves provided.

Process fugitive emissions normally associated with batch and continuous plants from the hot side screens, bins, elevators and pug mill have been eliminated in the drum mix process. There may be, however, a certain amount of fugitive VOC and liquid aerosol produced from transport and handling of hot mix from the drum mixer to the storage silo, if an open conveyor is used, and also from the beds of trucks. The open dust sources associated with drum mix plants are similar to those of batch or continuous plants, with regard to truck traffic and aggregate handling operations.

8.1.3 Representative Facility

Factors for various materials emitted from the stack of a typical asphaltic concrete plant are given in Table 8.1-5, and the characteristics of such a plant are shown in Table 8.1-6. With the exception of aldehydes, the materials listed in Table 8.1-6 are also emitted from the mixer, but in concentrations 5 to 100 fold smaller than stack gas concentrations, and they last only during the discharge of the mixer.

Reference 16 reports mixer emissions of SO_x, NO_x, and VOC as "less than" values, so it is possible they may not be present at all. Particulates, carbon monoxide, polycyclics, trace metals and hydrogen sulfide were observed at concentrations that were small relative to stack amounts. Emissions from the mixer are thus best treated as fugitive.

All emission factors for the typical facility are for controlled operation and are based either on average industry practice shown by survey or on results of actual testing in a selected typical plant.

An industrial survey[16] showed that over 66 percent of operating hot mix asphalt plants use fuel oil for combustion. Possible sulfur oxide emissions from the stack were calculated, assuming that all sulfur in the fuel oil is oxidized to SO_x. The amount of sulfur oxides actually released through the stack may be attenuated by water scrubbers, or even by the aggregate itself, if limestone is being dried. Number 2 fuel oil has an average sulfur content of 0.22 weight percent.

Emission factors for nitrogen oxides, nonmethane volatile organics, carbon monoxide, polycyclic organic material, and aldehydes were determined by sampling stack gas at the representative asphalt hot mix plant.

TABLE 8.1-5. EMISSION FACTORS FOR SELECTED GASEOUS POLLUTANTS FROM A CONVENTIONAL ASPHALTIC CONCRETE PLANT STACK[a]

Material emitted[b]	Emission Factor Rating	Emission factor[c] g/Mg	Emission factor[c] lb/ton
Sulfur oxides (as SO_2)[d,e]	C	146S	0.292S
Nitrogen oxides (as NO_2)[f]	D	18	0.036
Volatile organic compounds[f]	D	14	0.028
Carbon monoxide[f]	D	19	0.038
Polycyclic organic material[f]	D	0.013	0.000026
Aldehydes[f]	D	10	0.02
Formaldehyde	D	0.075	0.00015
2-Methylpropanal (isobutyraldehyde)	D	0.65	0.0013
1-Butanal (n-butyraldehyde)	D	1.2	0.0024
3-Methylbutanal (isovaleraldehyde)	D	8.0	0.016

[a]Reference 16.
[b]Particulates, carbon monoxide, polycyclics, trace metals and hydrogen sulfide were observed in the mixer emissions at concentrations that were small relative to stack concentrations.
[c]Expressed as g/Mg and lb/ton of asphaltic concrete produced.
[d]Mean source test results of a 400 plant survey.
[e]Reference 21. S = % sulfur in fuel. SO_2 may be attenuated 50% by adsorption on alkaline aggregate.
[f]Based on limited test data from the single asphaltic concrete plant described in Table 8.1-6.

TABLE 8.1-6. CHARACTERISTICS OF A REPRESENTATIVE ASPHALTIC CONCRETE PLANT SELECTED FOR SAMPLING[a]

Parameter	Plant sampled
Plant type	Conventional, permanent, batch plant
Production rate, Mg/hr (tons/hr)	160.3 ± 16% (177 ± 16%)
Mixer capacity, Mg (tons)	3.6 (4.0)
Primary collector	Cyclone
Secondary collector	Wet scrubber (venturi)
Fuel	Oil
Release agent	Fuel oil
Stack height, m (ft)	15.85 (52)

[a]Reference 16, Table 16.

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APPENDIX A

REFERENCE 1 AND SUPPORTING DATA

Control of ASPHALTIC CONCRETE PLANTS in Los Angeles County*

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Introduction

The phenomenal growth of population in Southern California during the last two decades has resulted in large demands for asphaltic concrete. To meet these demands, in Los Angeles County alone, 48 asphaltic concrete plants have been built which produce an average of 14,000 tons per day.

Prior to the installation of well-designed air pollution control equipment, dust losses from asphaltic concrete plants were nearly 25 tons per day. In 1949, the Air Pollution Control District of Los Angeles County adopted a rule which limited the discharge of dust from each of these plants to 40 pounds per hour.[1] To meet this prohibition, it became necessary to install dust collection equipment capable of high collection efficiencies. This was accomplished by the use of centrifugal or impingement type scrubbers which provided collection efficiencies, in most cases, of 90 percent or greater. The design of these control devices has improved over the years, and as described later in this paper, total emissions have decreased substantially in spite of increased production.

Description of Basic Equipment

Generally, an asphaltic concrete plant consists of a rotary dryer, screening and classifying equipment, an aggregate weighing system, a mixer, storage bins and conveying equipment. Sand and aggregate are charged from bins into a rotary dryer. The dried aggregate at the lower end of the dryer is mechanically conveyed by a bucket elevator to the screening equipment where it is classified and dumped into storage bins. Weighed quantities of the sized products are then dropped into the mixer along with asphalt where the batch is mixed and dumped into awaiting trucks for transportation to the paving site. The combustion gases and fine dust from the rotary drier are exhausted through a precleaner which is usually a single cyclone, but twin or multiple cyclones and other devices are also used. The precleaner catch is then discharged back into the bucket elevator where it continues in process with the main bulk of the dried aggregate. The air outlet of the precleaner is vented to air pollution control equipment.

Air Pollution Control Equipment

In Los Angeles County two principal types of control equipment have evolved from many types employed over the years—the multiple centrifugal type spray chamber and the baffled type spray tower. Of these two types, the multiple centrifugal type spray chamber (Fig. 1) has proved to be the more efficient. It consists of two or more internally fluted cylindrical spray chambers in which the dust-laden gases are admitted tangentially at high velocities. Each of these chambers is identical in size and has dimensions approximately

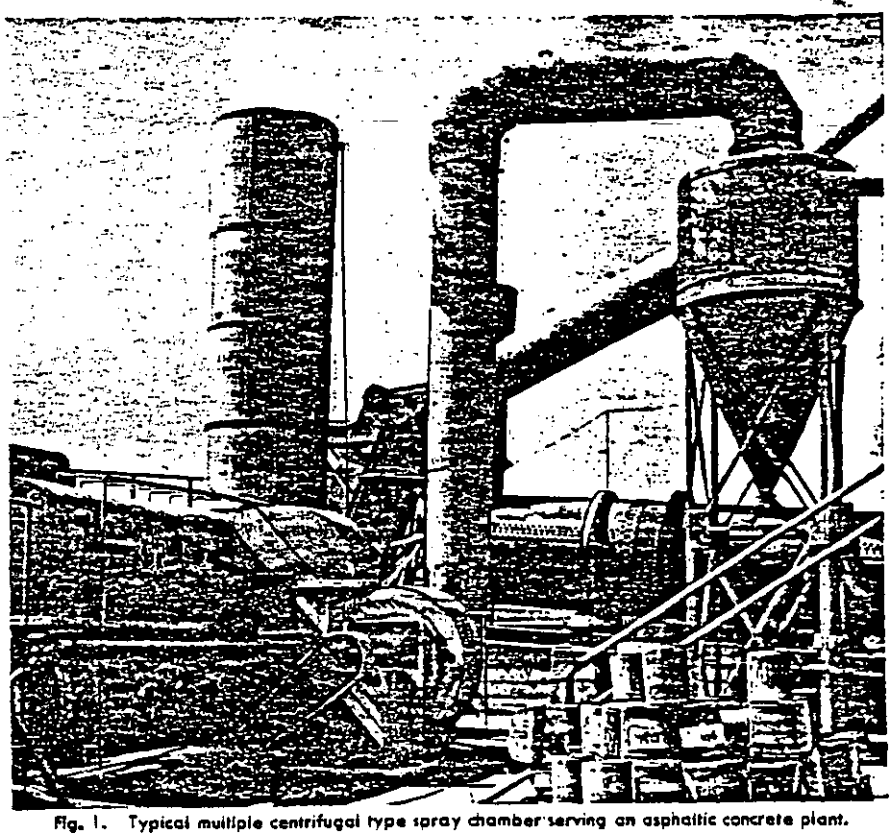


Fig. 1. Typical multiple centrifugal type spray chamber serving an asphaltic concrete plant.

* Presented at the 52nd Annual Meeting of APCA, Statler Hotel, June 21–26, 1959, Los Angeles, Calif.

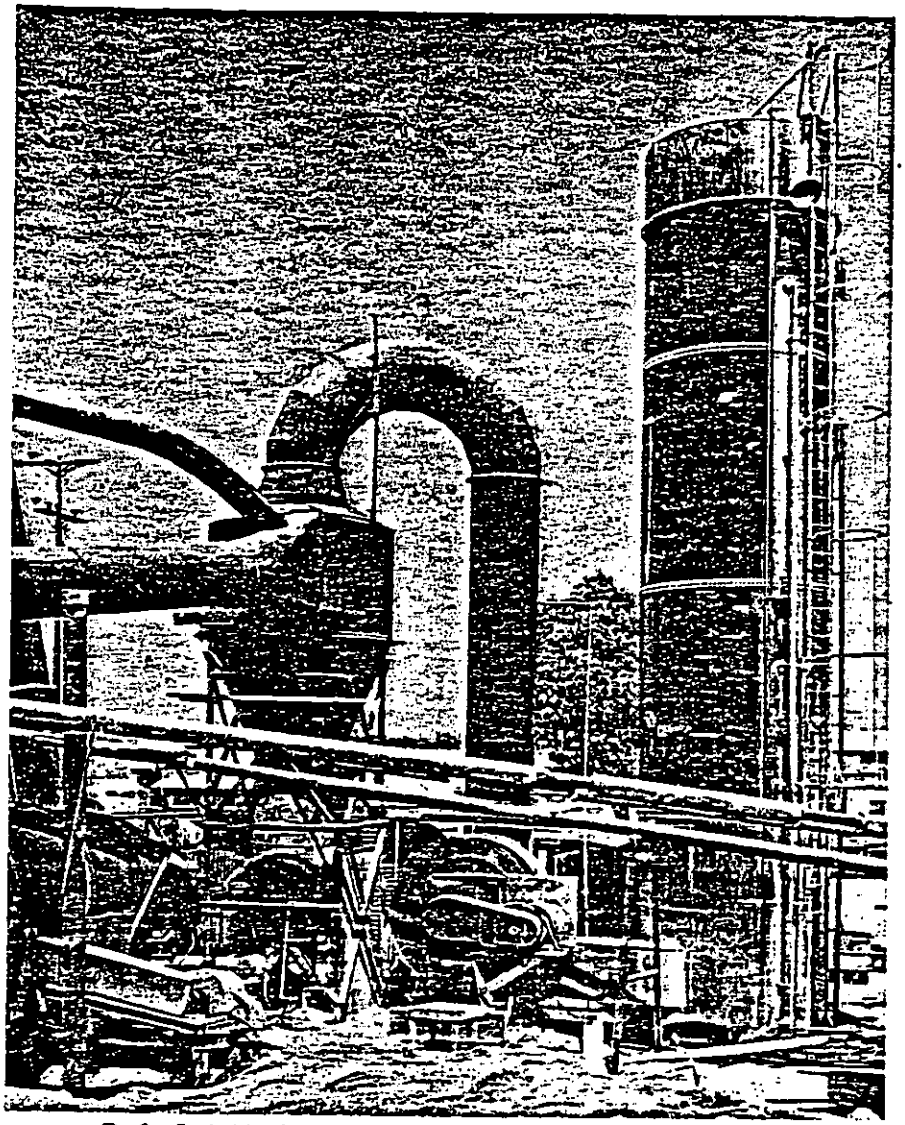


Fig. 2. Typical baffled type spray tower serving an asphaltic concrete plant.

6 ft diam x 15 ft long. Usually five to 10 spray nozzles are located evenly spaced within each chamber. Water rates to the nozzles are usually in the range of 70 to 250 gpm at 50 to 100 psi and the water generally is not recirculated. In the baffled type spray tower (Fig. 2), there have been many variations in designs, but fundamentally, each consists of a chamber which is baffled to force the gases to travel in an S-shaped pattern, encouraging impingement of the dust particles against the sides of the chamber and the baffles. Water spray nozzles are located between the baffles and water rates through the spray heads usually vary between 100 to 300 gpm at 50 to 100 psi.

In addition to venting the dryer, the dust collection system also ventilates several other dust sources which include: (1) the lower end of the dryer where the stationary burner box attaches to the rotary dryer; (2) the aggregate screening and classifying system; (3) the bucket elevator; (4) the aggregate storage bins; and (5) the weigh hopper.

Asphaltic concrete plants vary in size with the majority capable of producing 100 to 150 tons per hour. However, in the last two or three years, several plants have been installed in Los Angeles County which are classified as 6000-pound plants, capable of producing 200 to 250 tons per hour.

The major source of dust originates from the rotary dryer. Very little work has been done in the study of dust emissions from rotary dryers. Friedman and Marshall[2] obtained data showing that dryer dust emissions, expressed as percent of feed, increase with air mass velocity, increase with increasing rate of rotation, are independent of dryer slope, and decrease with increasing feed rate. The absolute amount of dryer

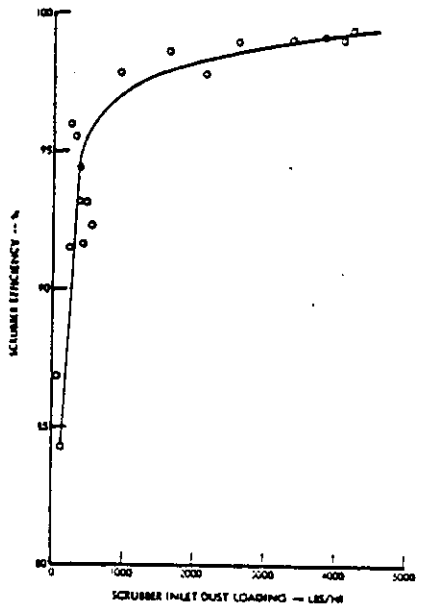


Fig. 3. Relationship between scrubber inlet dust loading and scrubber collection efficiency.

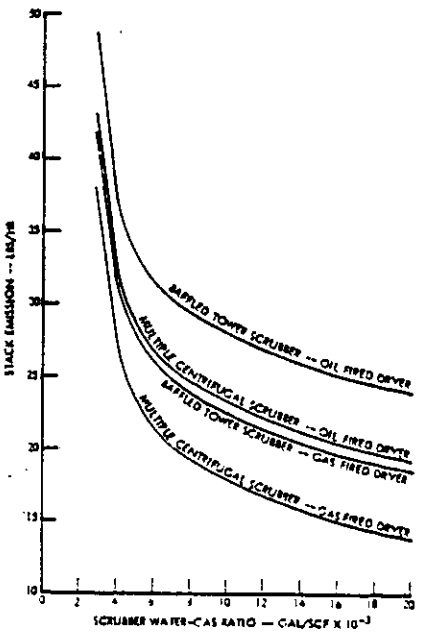


Fig. 4. Effect of scrubber water-gas ratio on stack emissions at average aggregate fines rate in the dryer feed.

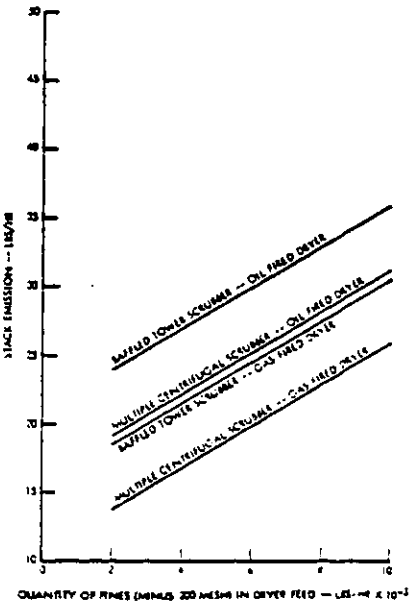


Fig. 5. Effect of aggregate fines rate on stack emissions at average water-gas ratio.

DATA USED IN TABLE 3-3

Table I—Test Data from Asphaltic Concrete Plants Controlled by Scrubbers

Test Number	Scrubber Inlet Dust Loading, Lb/Hr	Stack Emission, Lb/Hr, x_1	Aggregate Fines Rate,[a] Lb/Hr × 10^{-1}, x_2	Water-Gas Ratio, Gal/1000 scf, x_3	Log x_3	Type of Scrubber[b]	Type of Fuel	Production, Tons/Hr	Gas Effluent Volume, scfm
C-357	940	20.7	9.55	6.62	0.82	C	Oil	183.9	23,100
C-382	427	35.6	4.46	3.94	0.60	C	Oil	96.9	19,800
C-379	4110	37.1	8.35	6.38	0.81	C	Oil	174.0	26,200
C-355	2170	47.0	14.00	6.81	0.83	C	Oil	209.1	25,700
C-372B	121	19.2	2.29	10.99	1.04	C	Oil	142.9	18,200
C-372A	76	10.0	2.84	11.11	1.05	C	Gas	158.0	18,000
C-369	352	24.4	4.75	5.41	0.73	C	Oil	113.0	16,100
C-393	4260	26.9	4.05	12.01	1.08	T	Oil	92.3	19,500
C-354	—	27.8	6.37	6.10	0.79	T	Oil	118.4	7,720
C-185	1640	21.3	5.22	19.40	1.29	T	Oil	137.8	18,700
C-173	—	31.0	8.85	20.40	1.31	T	Oil	184.2	17,000
Outside lab.	—	33.5	7.52	11.01	1.04	T	Oil	144.6	23,700
C-379	3850	30.3	6.50	5.92	0.77	C	Gas	191.3	28,300
C-337	305	13.6	2.51	11.11	1.05	C	Oil	114.6	24,300
Outside lab.	—	21.1	3.73	7.28	0.86	T	Gas	124.4	15,900
C-234	372	21.2	2.53	5.70	0.76	T	Gas	42.0	17,200
C-426	2620	25.5	10.20	7.75	0.89	C	Oil	182.0	22,000
C-417	560	39.9	3.05	2.94	0.47	C	Oil	138.9	24,600
C-425	485	32.9	2.89	4.26	0.63	C	Oil	131.4	18,000
Outside lab.	—	25.5	6.59	6.60	0.82	C	Gas	131.7	18,200
C-385	212	17.5	4.89	4.56	0.66	C	Oil	174.3	20,000
C-433	266	11.0	5.96	8.12	0.91	C	Gas	114.5	19,600
C-422(1)	—	26.6	7.14	4.90	0.69	C	Oil	198.0	21,000
C-422(2)	—	37.0	3.34	3.02	0.48	C	Oil	152.0	22,200
C-418	3400	30.8	9.35	8.90	0.95	T	Oil	116.5	17,100
Totals		667.4	146.93		21.33				
Averages		26.7	5.9		0.85				

[a] Quantity of fines (minus 200 mesh) in dryer feed.
[b] C = Multiple centrifugal type spray chamber. T = Baffled tower scrubber.

dust, in weight per unit time, increases with feed rate. Dust emissions depend to a large extent on the particle size distribution of the dryer feed. While the dust from the rotary dryer is undoubtedly the greatest source, the dust collected from the vibrating screens, the bucket elevator, the bins and the weigh hopper is also considerable in quantity. In one plant, 2000 lb/hr of particulate matter containing 39.7 percent of 0 to 10 micron material was produced by these secondary sources.[3]

Study of Stack Test Data

In the process of granting permits to operate, many stack tests were conducted by the District to insure that each plant was operating in compliance with air pollution laws. As these data became available, a study was made to determine which variables were most significant in affecting emissions to the atmosphere. A preliminary observation disclosed that the water scrubber efficiency varied with the scrubber inlet dust loading as shown in Fig. 3. Higher dust collection efficiencies were obtained at the higher inlet dust loadings. Plants with less effective cyclone precleaning had, on the average, larger particles entering the water scrubber, and consequently better scrubber collection efficiencies were obtained. In fact, scrubber efficiency was so dependent upon the degree of precleaning that the effect of other variables on collection efficiency was completely masked in the available data. However, the fractional collection efficiency of particles larger than 10 microns in diameter proved to be 99.7 percent. Consequently, the variables and operating conditions which affect the amount and collection efficiency of the 0 to 10 micron fraction should be reflected in the absolute stack emissions. This was found to be the case. The magnitude of the stack emissions were found to depend mainly upon the scrubber water-gas ratio, the type of fuel used in the rotary dryer, the type of scrubber, and the quantity of minus 200-mesh material (minus 74 microns) processed in the dryer.[4] It would be expected that the particle size distribution of the minus 200-mesh fraction of the dryer feed would have a large effect on stack losses, but sufficient data were not available to investigate it.

Twenty-five source tests of asphaltic concrete plants were available (from some 115 tests which have been per-

DATA USED IN TABLE 3-3

Table II—Collection Efficiency Data for Scrubbers Serving Asphaltic Concrete Plants

Dust Particle Size, Microns	Test Report Series, C-393 Inlet, %	Outlet, %	Efficiency, %	Test Report Series, C-369 Inlet, %	Outlet, %	Efficiency, %	Test Report Series, C-372A Inlet, %	Outlet, %	Efficiency, %
0–10	13.0	99.3	95.2	76.4	79.9	92.8	78.0	83.0	85.0
10–20	71.1	0.0	100.0	6.3	3.8	96.0	18.0	5.0	96.2
20–44	9.6	0.0	100.0	2.8	2.0	95.0	2.0	1.0	93.3
44+	6.3	0.7	99.3	14.5	14.3[a]	93.1	2.0	11.0[a]	26.5

Dust Particle Size, Microns	Test Report Series C-372B Inlet, %	Outlet, %	Efficiency, %	Test Report Series C-422(1) Inlet, %	Outlet, %	Efficiency, %
0–10	91.0	82.0	85.7	80.4	73.2	—
10–20	9.0	3.0	99.4	18.6	5.1	—
1–44	0.0	2.0	—	1.0	4.5	—
44+	0.0	13.0[a]	—	0.0	17.2	—

[a] Microscopic examination indicated that the outlet samples were agglomerated.

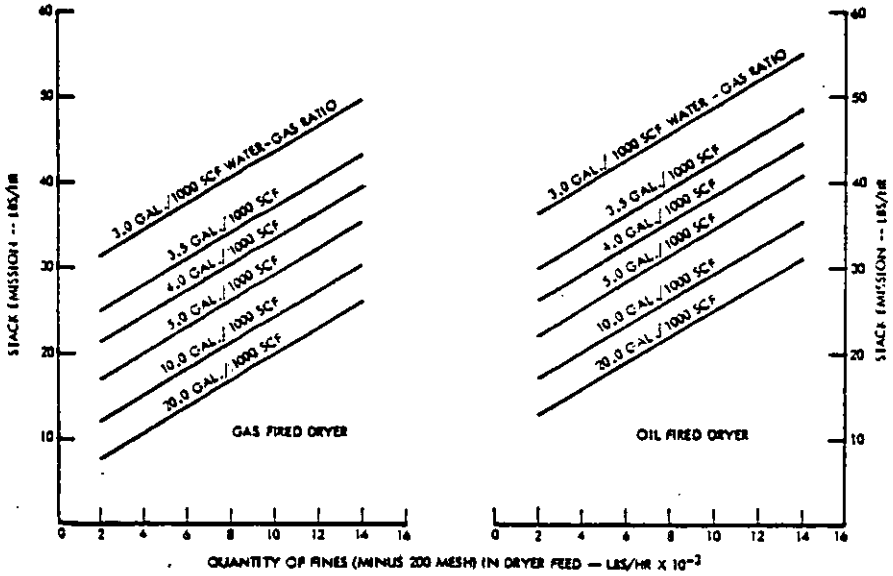


Fig. 6. Emission prediction curves for multiple centrifugal scrubbers serving asphaltic concrete plants.

formed since 1949) which had sufficient data to attempt to correlate the major variables affecting stack losses. Aggregate feed rates, screen size analyses, scrubber water and gas rates, as well as particulate matter emissions to the atmosphere were obtained during each of these tests. The data are tabulated in Tables I and II. The aggregate dryers were fired with PS 300 or heavier oils during 19 of the tests and natural gas fired during six. Seventeen of these tests were performed on multiple centrifugal type scrubbers with spiral baffles and tangential entrances. The other eight tests were performed on simple baffled tower scrubbers. A curvilinear multiple correlation was required to represent the data satisfactorily. Ezekiel's[6] graphical procedure of successive approximations was used to fit the curves (see Appendix for correlation methods).

Effect of Variables on Scrubber Emissions

The effect of scrubber water-gas ratio on stack emissions is shown in Fig. 4, for multiple centrifugal type scrubbers and baffled tower scrubbers, with the aggregate fines rate (the minus 200-mesh fraction) held constant at the average. Low scrubber water-gas ratios are more than proportionately less effective than higher ratios. Possibly, the water rate was insufficient for good spray coverage for ratios in the lower ranges.

The effect of aggregate fines rate on stack emissions at constant water-gas ratio is shown in Fig. 5 for multiple centrifugal type scrubbers and baffled tower scrubbers. Stack emissions increase linearly with an increase in the amount of minus 200-mesh material processed.

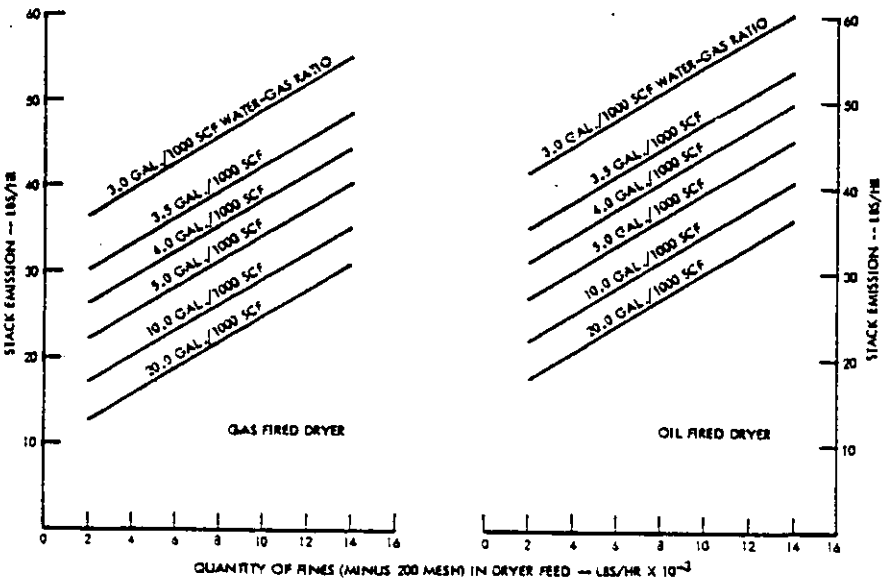


Fig. 7. Emission prediction curves for baffled tower scrubbers serving asphaltic concrete plants.

Stack emissions were 5.1 lb/hr higher when the dryer was oil fired, rather than gas fired. The difference is believed to represent particulate matter in or formed by the fuel oil, rather than additional dust from the dryer and mixer. It has been similarly observed that burning heavy fuel oils in other kinds of combustion equipment results in higher emissions of particulate matter. For example, glass furnaces discharge significantly more particulate matter when fired by PS 300 or heavier fuel oils than when natural gas or light fuel oils are used.[6]

As expected, centrifugal type water scrubbers were more effective than simple baffled tower water scrubbers. The difference averaged 5.0 lb/hr at constant aggregate fines rate and constant water-gas ratio.

The data, even when corrected for the variables studied, tend to scatter rather badly. However, the results do represent average trends of plants operating in the Los Angeles area. Curves are presented in Fig. 6 and 7 from which the most likely stack emissions can be predicted for oil and gas fired plants with either multiple centrifugal or baffled tower scrubbers. These curves present emissions for various scrubber water-gas ratios and aggregate fines rates.

During the course of conducting several particle size analyses of scrubber inlet and outlet dust, an unusual observation was made. In all of these tests as shown in Table II, the fractional collection efficiency of the 44+ micron material was less than for the 10–20 and the 20–44 micron fractions, which of course is opposite to what would normally be expected. However, microscopic examination of the samples indicated that the particles in the scrubber outlet were agglomerated. Apparently, the fine particles agglomerate within the scrubber, but part of the resulting agglomerates escape to the atmosphere. This potentially recoverable material constitutes five to 10 percent of the scrubber emissions. However, these emissions are minor and even perfect collection of this material would not reduce total emissions over 3.5 lb/hr.

Survey of Dust Emissions in Los Angeles County

In order to evaluate the effect of the control program on dust emissions from the asphaltic concrete industry, it was necessary to acquire information concerning the number of plants in operation, emissions of dust to the atmosphere, amount of asphaltic concrete produced, and volume of air handled.

To obtain the data on production, number of plants, types of controls and operating schedules, a questionnaire was devised and sent to each company operating an asphaltic concrete plant. The data obtained from this survey indicated that in 1957 there were 19 companies

operating 48 plants in Los Angeles County. These plants produced a total of 14,000 tons per day. The data also indicated that asphaltic concrete was produced over a 13-hr day with a maximum hourly output of 1200 tons.

To augment the data obtained from this survey and to make comparisons with data obtained from previous surveys, the analytical test data in the District's files on asphaltic concrete plants were studied. From these studies, average yearly dust emissions to the atmosphere were determined. During the early stages of the development of the control program, many stack tests disclosed emissions of dust in excess of the weight per hour allowed. As the design of control equipment improved, violations became less frequent. During recent years, excessive emissions could be traced to either poor experimental scrubber designs, or more frequently to poor maintenance. It was observed that even well-designed scrubbers would emit excessive dust if a sound maintenance program was not being enforced.

Figure 8 illustrates the effect of the increasing efficiency of the control equipment from 1948 to 1958. Prior to the development of the control program, little or no control devices were installed and an average of five pounds of dust were emitted per ton of asphaltic concrete produced. As the control program progressed and the efficiency of control equipment was increased, dust emissions were reduced until today only 0.15 pound is emitted per ton of asphaltic concrete produced. The major reduction of dust was accomplished between 1948 and 1950. During this period, an average reduction of 150 lb/hr per plant was achieved. From 1950 to the present time, an average reduction of 12 lb/hr per plant has been accomplished due to improvements in controls and better maintenance programs.

The increased efficiency of the control equipment was accomplished even though the average volume of gases handled per plant has increased from 13,000 standard cubic feet per minute in 1951 to 21,000 standard cubic feet per minute in 1958. Figure 9 illustrates this increase in volume. A reduction in volume between 1948 and 1951 is believed to be partially due to conservation of gas volume to allow smaller control devices to be installed. Subsequent to 1951, better control of dust emissions from sources other than the dryer required an increase in gas volume. Moreover, plants have increased in size in recent years.

The data obtained from surveys conducted periodically on the asphaltic concrete industry show that production has increased since 1948 from an average of 10,000 tons per day to more than 14,000 tons per day in 1957 (Fig. 10), an increase of 40 percent. During the same period, dust emissions decreased from 25 tons per day to 1 ton per day, a decrease of 96 per cent overall.

Conclusions

In conclusion, it is emphasized that the variables studied only represent average trends of asphaltic concrete plants in Los Angeles County. With this point in mind, it can be concluded that:

1. Multiple centrifugal scrubbers have proved to be more efficient than baffled towers.
2. Scrubber water-gas ratio is equally important in both types of scrubbers. The best utilization of water is achieved up to a ratio of six gallons per 1,000 standard cubic feet of gas. Above this ratio, efficiency still increases within the bounds studied, but at a lesser rate.
3. Scrubber stack emissions increase linearly with an increase in the amount of minus 200-mesh material charged to the dryer.
4. The burning of PS 300 or heavier fuel oils rather than natural gas results in higher stack emissions. Under constant conditions, an increase of approximately five pounds per hour was observed. Although the available data are not conclusive, it appears that dust emissions are significantly decreased when PS 200 oil is substituted for PS 300 oil.

Through the use of scrubbers, dust emissions from asphaltic concrete plants have been reduced from a total of 25 tons per day to 1 ton per day. If this is related to the increase in production over the 10-year period then the control program is responsible for a net removal of 34 tons per day of dust from the Los Angeles County atmosphere.

REFERENCES

1. Rule 54, Rules and Regulations of the Los Angeles County Air Pollution Control District. In essence, this rule limits the amount of dust and fumes discharged to the atmosphere in any one hour from any source based upon the process weight. For example, if 100 tons per hour of sand and aggregate are charged to the dryer of an asphaltic concrete plant, the process weight is then 200,000 lb/hr. The rule states that for process weights of 60,000 lb/hr or more, the maximum weight of dust and fumes discharged to the atmosphere shall not exceed 40 lb/hr.
2. S. J. Friedman and W. R. Marshall, Jr., "Studies in Rotary Drying," *Chem. Eng. Prog.*, 45: 8, p. 482 (August, 1949).
3. Los Angeles County Air Pollution Control District, Test Report Series C-426, unpublished reports.
4. R. M. Ingels and G. S. Richards, Los Angeles County Air Pollution Control District, unpublished report.
5. M. Ezekiel, Methods of Correlation Analysis, 2nd Edition, p. 220, John Wiley and Sons, New York (1941).
6. Los Angeles County Air Pollution Control District, Test Report Series C-372, unpublished report.

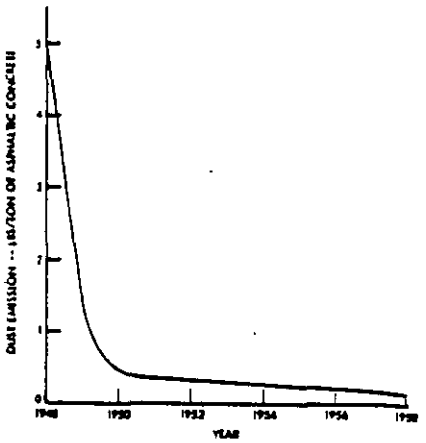


Fig. 8. Reduction of dust emissions from asphaltic concrete plants in Los Angeles County during the period 1948 to 1958.

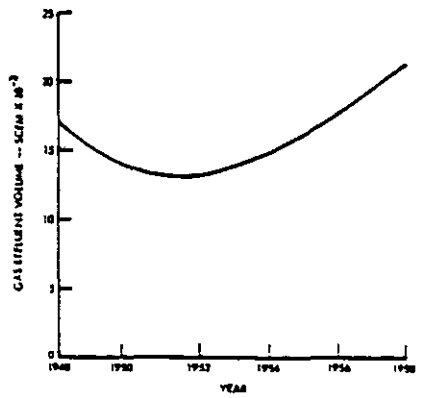


Fig. 9. Asphaltic concrete plant average scrubber effluent volume in Los Angeles County during the period 1948 to 1958.

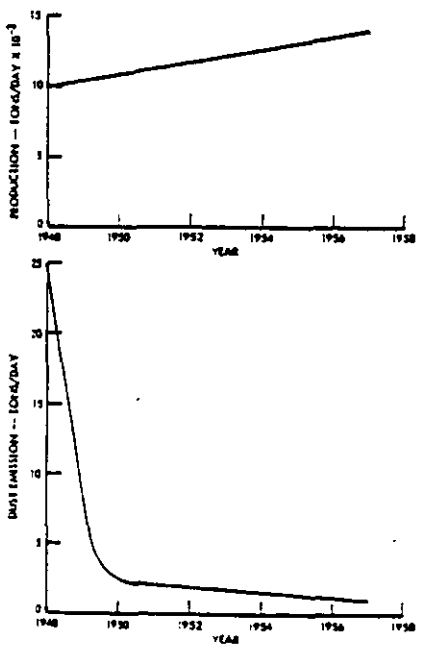


Fig. 10. Average daily production and total dust emissions from asphaltic concrete batching plants in Los Angeles County.

Summary of L.A. Particle Size Data[a]

Test Series No.	Inlet Dust Loading (lbs./hr.)	Outlet Dust Loading (lbs./hr.)	Type of Scrubber[b]	Production Rate (Tons/hr.)	Inlet Particle Size (% Weight)				Outlet Particle Size (% Weight)			
					0-10 μm	10-20 μm	20-44 μm	>44 μm	0-10 μm	10-20 μm	20-44 μm	>44 μm
C-393	4260	26.9	T	92.3	13.0	71.1	9.6	6.3	99.3	0	0	0.7
C-369	352	24.4	C	113.0	76.4	6.3	2.8	14.5	79.9	3.8	2.0	14.3[c]
C-372A	76	10.0	C	158.0	78.0	18.0	2.0	2.0	83.0	5.0	1.0	11.0[c]
C-372B	121	19.2	C	142.9	91.0	9.0	0	0	82.0	3.0	2.0	13.0[c]
C-422(1)	—	26.6	C	198.0	80.4	18.6	1.0	0	73.2	8.1	4.5	17.2

a. From: Ingel, et al, "Control of Asphaltic Concrete Plants in Los Angeles County," J. Air Pollut. Control Assoc., 10(1): 29-33, Feb. 1960.

b. C = Multiple centrifugal spray scrubber; T = Baffled spray tower

c. Microscopic examination indicated agglomerated particles.

JSK - 5/7/82

South Coast
AIR QUALITY MANAGEMENT D

HEADQUARTERS, 9150 E. FLAIR DR., EL MONTE, CA 91731
ANAHEIM OFFICE, 1610 E. BALL RD., ANAHEIM, CA 92805 . (714) 991-7200
CARSON OFFICE, 950 DOVLEN PL., SPACE E, CARSON, CA 90746 . (213) 52
COLTON OFFICE, 22880 COOLEY DR., COLTON, CA 92324 . (714) 824-2660

Data Rating: C
Process
Fair Documentation
No Particle Size
Method Specified
However

May 25, 1

Mr. John S. Kinsey, Task Leader
Air Quality Assessment Section
Midwest Research Institute
425 Volker Blvd.
Kansas City, Missouri 64110

Re: EPA Contract 68-02-3158, Technical Directive No. 18

Dear Mr. Kinsey:

As per your request, dated May 24, 1982 we are enclosing the relevant data from test Nos. C-393 and C-426. We are sorry to inform you that the other five test reports you requested are no longer available.

Along with this letter an invoice for this service is being submitted.

If you have any questions please feel free to contact me.

Very truly yours,

William B. Krenz
Manager,
Source Testing and Monitoring
(213) 572-6485

WBK:lb

Enclosure

AIR POLLUTION CONTROL DISTRICT - COUNTY OF LOS ANGELES
434 SOUTH SAN PEDRO STREET - LOS ANGELES 13, CALIFORNIA

TEST CONDUCTED AT GRIFFITH COMPANY 1601 ALAMEDA STREET WILMINGTON, CALIFORNIA ON JULY 23, 1957

REPORT ON THE STACK ANALYSES OF THE DISCHARGE GASES FROM A WATER SCRUBBER SERVING A HOT ASPHALT PLANT DURING OIL FIRING

BY

H. E. McMAHON — SENIOR AIR POLLUTION ENGINEER

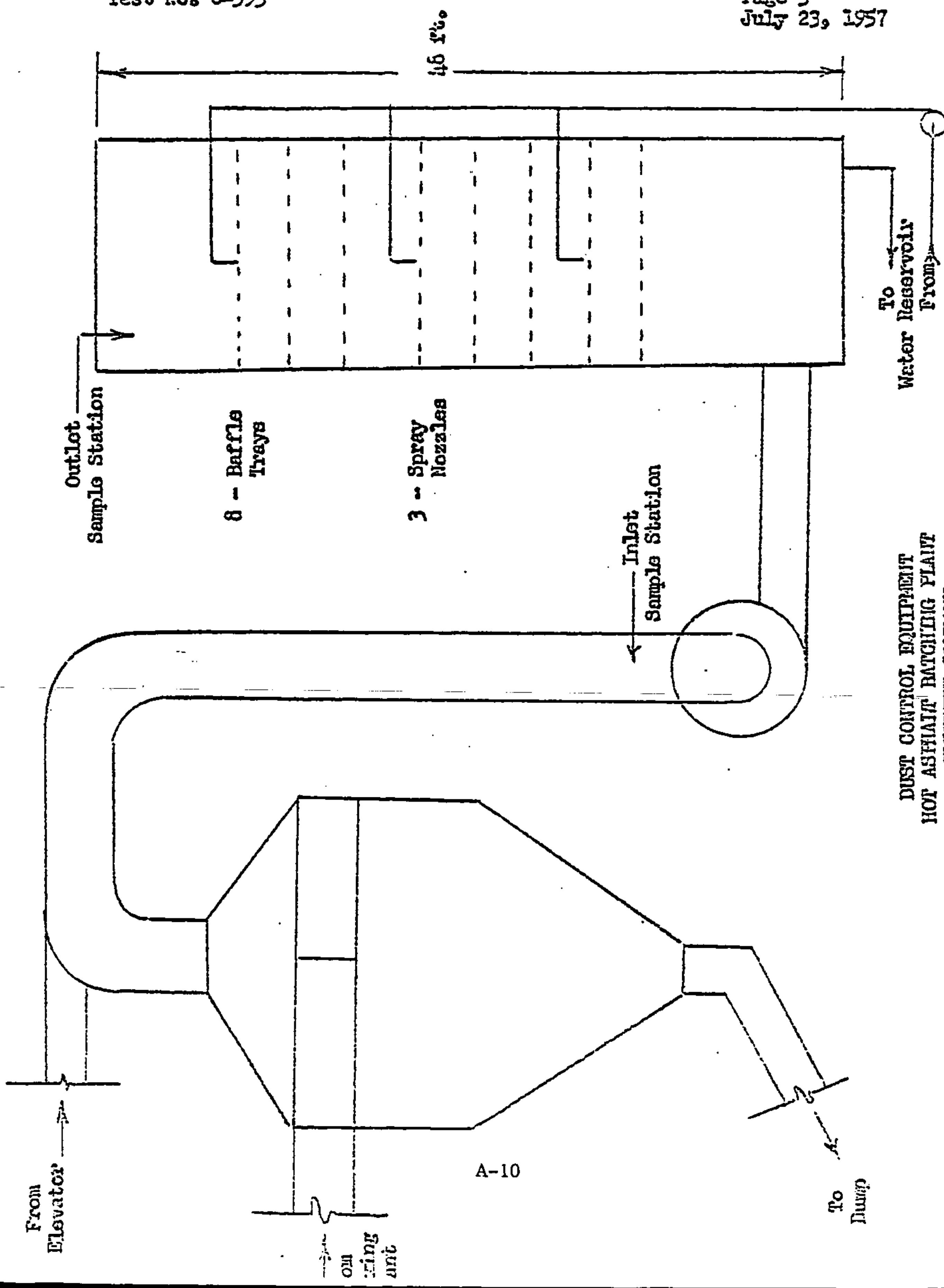
W. C. ROGERS — AIR POLLUTION ENGINEER

RESEARCH DIVISION REPORT NO. C-393

ISSUED SEP 19 1957

Test No. C-393

Page 3
July 23, 1957



DUST CONTROL EQUIPMENT
HOT ASPHALT BATCHING PLANT
GRIFFITH COMPANY
WILMINGTON, CALIFORNIA

AIR POLLUTIO(CONTROL DISTRICT - COUNTY (LOS ANGELES

SUMMARY SHEET

Name of Firm Griffith Company Test No. C-393

Location of Plant 1601 Alameda St., Wilmington, Calif. Date July 23, 1957

Collection Equipment Yes X No _____ Type Water scrubber

Specific Equipment Tested Water scrubbing tower serving hot asphalt plant

Length of Process Cycle _____ Time Cycle Begin _____ End _____

Total Process Weight _____ P.W./hr. 184,560

	Inlet	Outlet
Sample Station		
Time of Test Begin	1:15 P. M.	11:CO A. M.
End	1:31 P. M.	1:31 P. M.
Elapsed Time (Test)	16 min.	53 min.
Gas Volume SCFM (Standard Conditions)	20900	19500
Material Collected	Particulate Matter	
Grains/SCF	23.8	0.161
Grains/SCF at 12% CO_2		
Loss per hour in pounds	4260	26.9
Allowable Loss Lbs. per hour		40.0
Percent Moisture in Gases	11.4	8.1
Orsat Analysis (Dry Basis)		
Percent: CO_2	3.2	2.6
O_2	15.9	17.0
CO	0.0	0.0
N_2 (By diff.)	80.9	80.4
Combustibles - percent	2.6	7.1
Collection Efficiency - percent		99.4

Test Cond. By HMc - FN - WR

Approved By _____ *Data Comp. and Checked By* WR - PN

16.70079

Particle Size Analyses of Samples
(By Sedimentation Method)

	Inlet		Outlet	
	Wt. gms.	Wt. %	Wt. gms.	Wt. %
0-10μ	0.3286	13.0	0.3535	99.3
10μ-20μ	1.7977	71.1	-	-
20μ-44μ	0.2416	9.6	-	-
>44μ	0.1593	6.3	0.0029	0.7
	2.5272	100.0	0.3564	100.0

(THESE DATA USED IN TABLE 3-4)

SIEVE ANALYSES OF AGGREGATE

Percent of Sample by Weight

SIEVE SIZE	CONVEYOR				HOT BINS									
	No. 1	No. 2	No. 3	No. 4	No. 1	No. 2	No. 3	No. 4	No. 1	No. 2	No. 3	No. 4	No. 4	
	12:15 PM	12:34 PM	1:15 PM	2:05 PM	12:30 PM	1:00 PM	12:30 PM	1:00 PM	1:00 PM	12:30 PM	1:00 PM	12:30 PM	1:00 PM	
+ 10 Mesh	80.4	60.3	83.6	72.8	22.7	10.9	95.5	93.7	98.4	98.4	98.0	99.7	99.5	
- 10 +100 Mesh	16.4	33.3	12.9	22.5	66.2	70.0	4.1	5.8	1.0	1.0	1.2	0.1	0.2	
-100 +200 Mesh	1.6	3.5	1.6	2.4	6.0	8.0	0.1	0.2	0.2	0.2	0.1	0.0	0.1	
-200 Mesh	1.6	2.9	1.9	2.3	5.1	11.1	0.3	0.3	0.4	0.4	0.7	0.2	0.2	
TOTAL	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	

PM - MR

AIR POLLUTION CONTROL DISTRICT — LOS ANGELES COUNTY

Statement of Process Weight

COPY

Date July 23, 1957

Firm Name Griffith Company

Address 1601 N. Alameda

Time Cycle Started 11:05 AM 2:08 PM

Time of complete operating cycle in minutes 60 min.
(see 2 j. Rules & Regulations)

Raw material charged during this time — Material _____ Wt. in lbs. 184,560

do — Material _____ Wt. in lbs. _____

do — Material _____ Wt. in lbs. _____

do — Material _____ Wt. in lbs. _____

Solid fuel charged in pounds — Material _____ Wt. in lbs. _____

Total pounds _____

P.W. = $\frac{\text{Total pounds} \times 60}{\text{Total minutes}}$ = $\frac{\quad \times 60}{}$ = lbs./hr. 184,560

P.W. for 1st preceding cycle X

P.W. for 2nd preceding cycle X

P.W. for 3rd preceding cycle X

Sig. J. Heeden

Title Plant Foreman

RULES AND REGULATIONS OF THE AIR POLLUTION CONTROL DISTRICT

REGULATION I. GENERAL PROVISIONS RULE 2. DEFINITIONS

j. Process weight per hour. "Process weight" is the total weight of all materials, including solid fuels, introduced into any specific process, which process may cause any discharge into the atmosphere. The "process weight per hour" will be derived by dividing the total process weight by the number of hours in one complete operation from the beginning of any given process to the completion thereof, excluding any time during which the equipment is idle.

765 607 C 3-52

AIR POLLUTION CONTROL DISTRICT - COUNTY OF LOS ANGELES

TEST NO. C-393

DATE July 23, 1957

SUMMARY OF CALCULATIONS

NAME OF FIRM Griffith Company

DESCRIPTION OF EQUIPMENT TESTED Water scrubbing tower serving the hot asphalt plant.

1. Phase of Process Cycle Covered by Test

		Inlet	Outlet
2.	Sampling Station Location		
3.	Ave. Gas Vel. at Sampling Station (Ft/Sec)		
4.	Flue Gas Volume (SCFM)	20900	19500
5.	Sample Nozzle Diameter	8 mm	15 mm
6.	Sampling Rate, at Meter (CFM)	0.96	0.50
7.	Elapsed Time of Test (Minutes)	16	53
	Meter Vacuum - Average ("Hg)	7.6	2.2
9.	Meter Temperature - Average (°F)	88	79
10.	Volume of Gas Sampled, Meter Conditions (CF)	15.44	26.48
11.	Water Vapor Condensate (cc)	30	35
12.	Water Vapor Volume, Meter Conditions (CF)	2.0	1.8
13.	Total Sampled Volume, Meter Conditions (CF)	17.4	28.3
14.	Corrected Sample Volume - (SCF)	12.3	25.3
15.	Material Collected	Particulate Matter	
	Weight (gm.) a. Whatman thimble	0.059	0.006
	b. Water residue	18.3879	0.2576
	c.		
	Total Weight (gm.)	18.947	0.264
	Concentration grains/SCF	23.8	0.161
	Concentration grains/SCF @ 12% CO_2		
	Calculated Loss (Lbs. per hour)	4260	26.9

COLLECTOR EFFICIENCY

(If Collector Installed)

16.	Total material to collector (Lbs. per hour)	4260
17.	Total loss to atmosphere (Lbs. per hour)	26.9
18.	Total material collected (Lbs. per hour)	4233
19.	Percent efficiency	99.4

TEST COND. BY HMc - PN - WR

DATA COMP. & CHECKED BY WR - PN

AIR P[illegible]UTION CONTROL DISTRICT - COUNT[illegible]F LOS ANGELES
434 SOUTH SAN PEDRO STREET - LOS ANGELES 13, CALIFORNIA

TEST

CONDUCTED AT

GRIFFITH COMPANY HOT ASPHALT PAVING BATCH PLANT

1380 EAST ARROW HIGHWAY

IRWINDALE, CALIFORNIA

ON

FEBRUARY 7, 1958

REPORT

ON THE

DUST LOSS, PARTICLE SIZE DISTRIBUTION

AND COLLECTION EFFICIENCY OF EQUIPMENT

CONTROLLING EMISSIONS OF DUST FROM A

HOT ASPHALT PAVING BATCH PLANT

BY

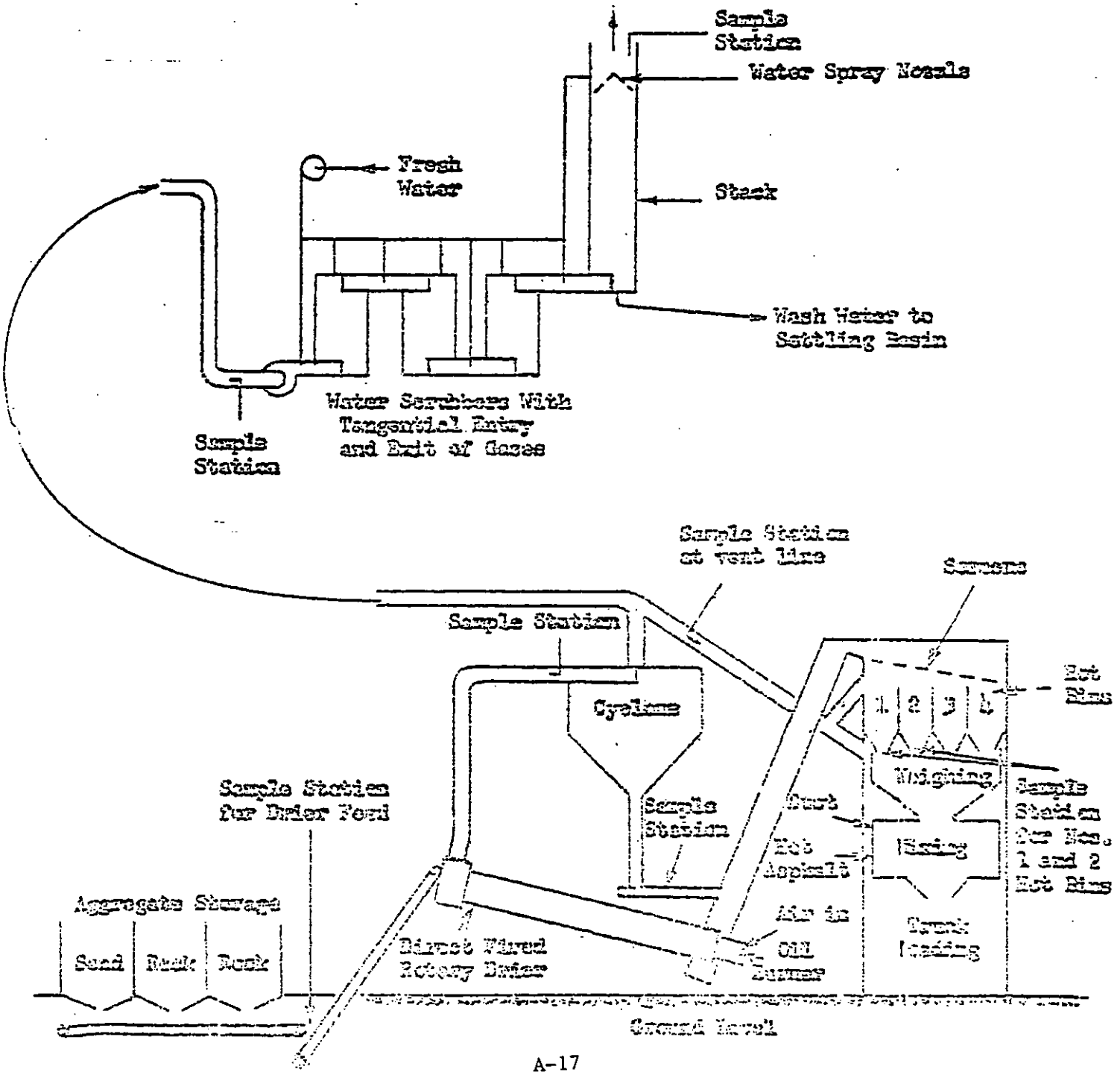
R. M. BURLIN — INTERMEDIATE AIR POLLUTION ENGINEER

H. W. LEONARD — AIR POLLUTION ENGINEER

ENGINEERING DIVISION REPORT NO. C-426

ISSUED MAR 24 1959

SCHEMATIC DIAGRAM OF
HOT ASPHALT PAVING BATCH PLANT



AIR (LLUTION CONTROL DISTRICT — LOS A(LES COUNTY

Statement of Process Weight Page 7
(COPY)

Date February 7, 1958

Firm Name Griffith Co.

Time Cycle Started

Address 1380 Arrow Hy.

Time of complete operating cycle in minutes
(see 2 j. Rules & Regulations)

Raw material charged during this time	Material	1 bin	Wt. in lbs.	1680
do	Material	2 "	Wt. in lbs.	1456
do	Material	3 "	Wt. in lbs.	1540
do	Material	4 "	Wt. in lbs.	644
Solid fuel charged in pounds	Material	40/50	Wt. in lbs.	280

Total pounds 5600 lbs.

P.W. = $\frac{\text{Total pounds} \times 60}{\text{Total minutes}} = \frac{\quad \times 60}{\quad}$ = lbs./hr. 182 TPH

P.W. for 1st preceding cycle
P.W. for 2nd preceding cycle
P.W. for 3rd preceding cycle

Sig. Al Pennington

Title Plant Foreman

RULES AND REGULATIONS OF
THE AIR POLLUTION CONTROL DISTRICT

REGULATION I. GENERAL PROVISIONS RULE 2. DEFINITIONS

j. Process weight per hour. "Process weight" is the total weight of all materials, including solid fuels, introduced into any specific process, which process may cause any discharge into the atmosphere. The "process weight per hour" will be derived by dividing the total process weight by the number of hours in one complete operation from the beginning of any given process to the completion thereof, excluding any time during which the equipment is idle.

76 S 607 C 3-52

AIR POLLUTION CONTROL DISTRICT - COUNTY OF LOS ANGELES

SUMMARY SHEET

Name of Firm Griffith Company Test No. C-426

Location of Plant 1380 E. Arrow Highway, Irwindale, Calif. Date February 7, 1958

Collection Equipment Yes X No _____ Type Cyclone and water scrubber

Specific Equipment Tested Cyclone and water scrubber

Length of Process Cycle Continuous Time Cycle Begin _____ End _____

Total Process Weight _____ P.W./hr. 364,000

Sample Station	Cyclone Inlet	Vent Line	Scrubber Inlet	Stack Outlet
Time of Test Begin	12:05	1:33	12:05	12:05
End	2:07	2:07	1:20	1:20
Sampling Time min.	60	34	60	60
Gas Volume SCFM (Standard Conditions)	21,000	2800	28,000	22,000
Material Collected	Dust			
Grains/SCF	37.2	81.8	10.9	0.135
Grains/SCF at 12% CO_2				
Loss per hour in pounds	6,700	2000	2,620	25.5
Allowable Loss Lbs. per hour	-	-	-	40
Percent Moisture in Gases	17.6	-	16.6	10.5
Orsat Analysis (Dry Basis)				
Percent: CO_2				
O_2				
CO				
N_2 (By diff.)				
Stack Gas Temperature, °F (Av.)	200	215	147	119
Stack Gas Velocity, ft/sec. (Av.)	49.7	70.2	43.2	14.3

Collection Efficiency: Cyclone - 91%
Scrubber - 99%

Test Cond. By _____

Approved By _____ *Data Comp. and Checked By* ERG - HL

Particle Size Distribution

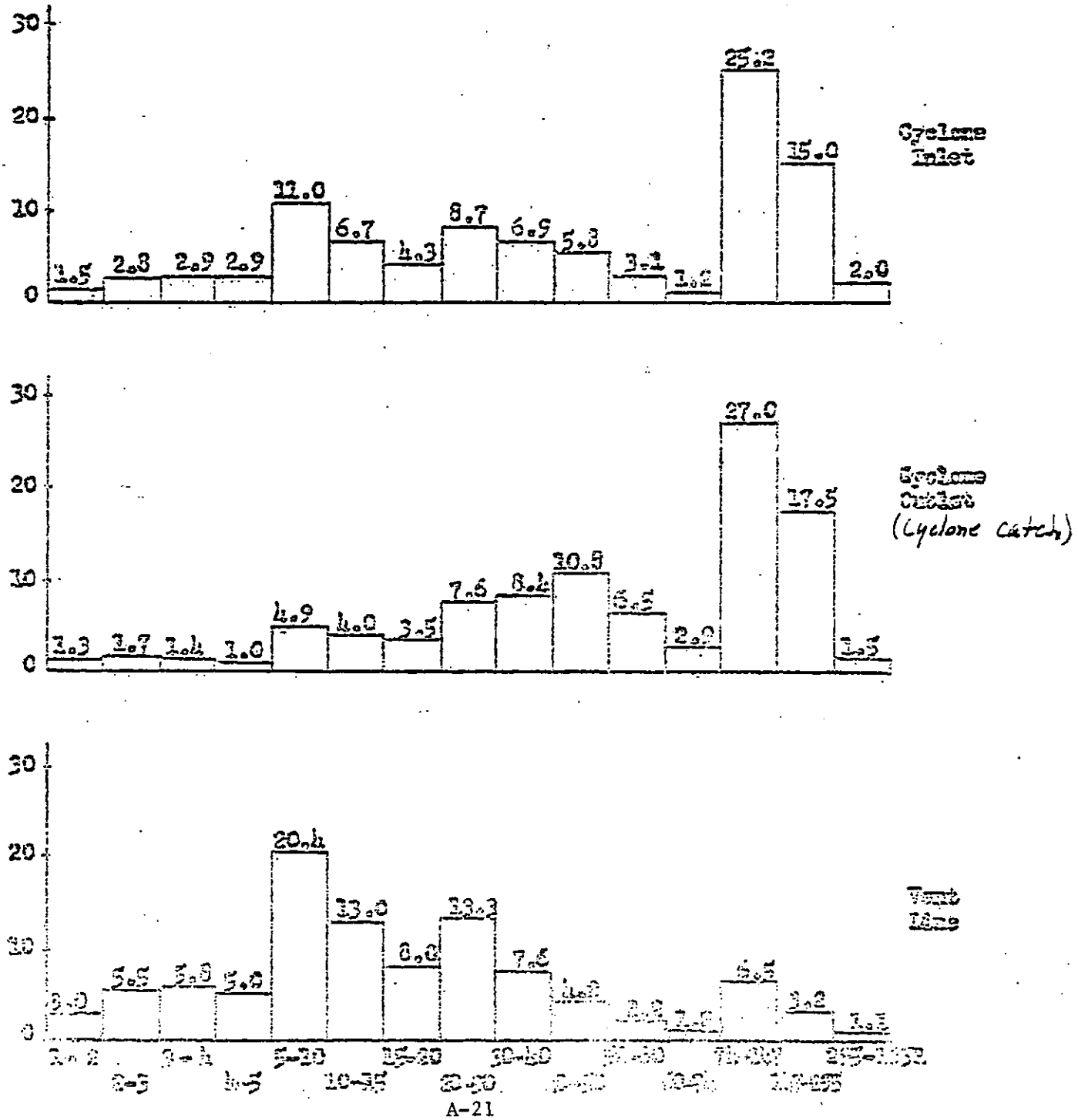
Weight % Less Than	SAMPLE STATION					
	Drier Feed	Bin No. 1	Bin No. 2	Cyclone Inlet	Cyclone Outlet	Vent Line
10 mesh (1651 microns)	29.2	92.7	6.3	100.0	100.0	100.0
48 mesh (295 microns)	9.4	31.8	0.6	98.0	98.5	98.9
100 mesh (147 microns)	4.5	14.5	0.5	83.0	81.0	95.7
200 mesh (74 microns)	2.8	8.4	0.5	57.8	54.0	89.2
60 microns				56.6	51.1	88.0
50 microns				53.5	44.6	85.8
40 microns				47.7	33.8	81.6
30 microns				40.8	25.4	74.0
20 microns				32.1	17.8	60.7
15 microns				27.8	14.3	52.7
10 microns				21.1	10.3	39.7
5 microns				10.1	5.4	19.3
4 microns				7.2	4.4	14.3
3 microns				4.3	3.0	8.5
2 microns				1.5	1.3	3.0
1 micron				0	0	0

(THESE DATA USED IN TABLE 3-5)

EDG - HL

Test No. 2-426

GRAPHS SHOWING PARTICLE SIZE DISTRIBUTION



AIR POLLU(ON CONTROL DISTRICT - COU(OF LOS ANGELES

TEST NO. C-426 PAGE 11 OF PA(

DATE February 7, 19

SUMMARY OF CALCULATIONS

NAME OF FIRM Griffith Company

DESCRIPTION OF EQUIPMENT TESTED 6000 lb. asphaltic concrete batch plant (oil fired) with 12' dia. cyclone and triple-tube centrifugal wet scrubber.

1. Phase of Process Cycle Covered by Test

		Cyclone Inlet	Vent Line	Scrubber Inlet	Stack Outlet
2.	Sampling Station Location				
3.	Ave. Gas Vel. at Sampling Station (Ft/Sec)	49.7	70.2	43.2	14.3
4.	Flue Gas Volume (SCFM)	21,000	2800	28,000	22,000
5.	Sample Nozzle Diameter (mm)	7	5	6.4	6
6.	Sampling Rate, at Meter (CFM)	1.3	0.66	0.83	0.80
7.	Elapsed Time of Test (Minutes)	60	34	60	60
8.	Meter Vacuum - Average ("Hg)	7.9	5.3	4.0	4.0
9.	Meter Temperature - Average (°F)	93	76	76	72
10.	Volume of Gas Sampled, Meter Conditions (CF)	77.6	22	49.8	47.8
11.	Water Vapor Condensate (cc)	215	-	160	88
12.	Water Vapor Volume, Meter Conditions (CF)	14.4	-	8.8	4.8
13.	Total Sampled Volume, Meter Conditions (CF)	92.0	22.3	58.6	52.5
14.	Corrected Sample Volume - (SCF)	63.7	17.8	49.2	44.5
15.	Material Collected				
	Weight (gm.) a. Thimble	0.005	-	0.010	0.012
	b. Filtered Dust	152.420	94.091	-	-
	c. Water residue	1.115	0.301	34.619	0.378
	Total Weight (gm.)	153.54	94.39	34.629	0.390
	Concentration grains/SCF	37.2	81.8	10.9	0.135
	Concentration grains/SCF @ 12% CO_2				
	Calculated Loss (Lbs. per hour)	6,700	2000	2,620	25.5

COLLECTOR EFFICIENCY

(If Collector Installed)

		Cyclone	Scrubber
16.	Total material to collector (Lbs. per hour)	6700	2620
17.	Total loss to atmosphere (Lbs. per hour)	620	25.5
18.	Total material collected (Lbs. per hour)	6100	2590
19.	Percent efficiency	91	99

TEST COND. BY

APPENDIX B

REFERENCE 3

Staub-Reinhalt. Luft Vol. 27 No. 7 July, 1967

UDC 628.511.4:662.613.13:625.85

DUST REMOVAL FROM THE WASTE GASES OF PREPARATION PLANTS FOR BITUMINOUS ROAD-BUILDING MATERIALS

by Dr.-Ing. Peter Wiemer

Technischer Überwachungs-Verein Rheinland e. V., Cologne

For many years problems connected with dust removal from the gases of drying drums in road building plants were the center of fruitless discussion. Although the opinions of the participants were not always free of vested interests, the deeper causes of the controversy lay in the unclear factual circumstances and in the inadequate knowledge in so extensive and complex a sphere. Many individual experiences are contradictory and some conclusions do not apply to installations elsewhere. Finally, the possibilities and limits of dust removal are not assessed correctly, even today.

Investigating the waste gases of drying drums

In 1963, the two Trade Associations of operators of such equipment (the "Bundesfachabteilung Strassenbau" in the "Hauptverband der deutschen Bauindustrie," and the "Bundesarbeitsgemeinschaft der Vereinigung der Teer- und Asphaltmakadam herstellenden Firmen") initiated research to resolve these basic problems. The project was offered to the "Hauptabteilung Wärme- und Kraftwirtschaft des TÜV Rheinland." This large-scale project was intended to examine, unprejudiced by, and independent of, all hitherto known data, the expected dust content in the drum waste gases, their dependence on starting material and the manufactured mixture, the specific properties of these dusts and, finally, dust removal, as practiced so far. The problem of drum utilization, the resulting waste-gas quantities and conditions, etc., were included. The measurements were carried out in 1964 according to a standardized program. In 1965, the results were used to prepare the draft for VDI Directive 2283 "Emission limits, preparation and mixing plants for bituminous road building materials." The final version will appear this year.

The number of such preparation plants operated in West Germany by these associations is estimated at some 1,700 to 1,800. A representative cross section through all these plants according to statistical principles was not possible for various reasons. Consequently, the plants to be investigated were selected by locality, raw material, size and differing levels of equipment, so that the measurements were sure to provide an extensive view of practical working conditions. Maximum drum load was agreed upon with the operators for the purpose of this investigation, and test days were adapted to include whatever were regarded as the most interesting mixtures.

Test results

The results of these first systematically planned and implemented series investigation, a total of 35 individual studies at 10 plants, are represented in Tables 1 to 3. They provide a clear view of the dusts leaving the drums with the waste gases, being subsequently almost completely retained in the dust collectors of the first and second stage, a small residue being finally emitted into the free air.

These series investigations having been completed, it was of interest to compare their results with data obtained from numerous other studies in similar plants. They are values obtained at many places in emission measurements performed at the behest of the authorities. Table 4 shows the results of 83 such studies in 27 plants. These measurements were made available to the author by various institutes. The many blank fields in this table (Table 4) which was compiled according to the same scheme as Table 3, emphasize the incompleteness of our knowledge, a situation which is quite inevitable when evaluation is based on conventional emission data which, though numerous, carry too little information. The series investigation has the further advantage of noting the occasionally high dust content in the raw gas.

TABLE 1. Drum sizes of the plants and existing dust collectors

Consec. No.	Plant No. and test No.	Mixture manufactured	Drum dimensions			Dust collector	
			Diam. (m)	Length (m)	Rated capacity (t/hr)	1st stage	2nd stage
1 — 5	A 1 — A 5	Fine asph. concr. 0/8	1.6	6	30/40	4 cyclones, 700 ϕ	Wet scrubber
6	B 2	Fine asph. concr. 0/8	1.8	9	60/80	21 cyclones, 410 ϕ	None
7	3	" " " "					
8	1	Base 0/30				+12 cyclones, 600 ϕ	
9	C 1	Fine asph. concr. 0/8	2.0	8	60/80	6 cyclones, 1,320 ϕ	Wet scrubber
10	2						
11	D 1	Fine asph. concr. 0/8	1.25	8	60/80	2 cyclones, 1,320 ϕ	Wet scrubber
12	4	" " " "					
13	2	Base 0/35					
14	3	" "					
15	E 3	Binder 0/12	2.0	8	60/80	Surface cooler	Fabric filter
16	1	Base 0/25					
17	2	" "					
18	F 1	Fine asph. concr. 0/8	1.8	15	75/100	6 cyclones, 1,000 ϕ	Wet scrubber
19	3	" " " "					
20	2	Base 0/35					
21	4	" "					
22	G 2	Fine asph. concr. 0/8	2.0	15	90/120	4 cyclones, 1, 180 ϕ	Wet scrubber
23	1	Binder 0/12					
24	H 1	Fine asph. concr. 0/8	1.8	9	37.5/50	18 cyclones	Wet scrubber
25	2	" " " "					
26	3	Base 0/25					
27	4	" " " "					
28	I 1	Fine asph. concr. 0/8	1.8	9	45/60	20 cyclones	Wet scrubber
29	2	" " " "					
30	3	Binder 0/18					
31	4	" "					
32	K 4	Fine asph. concr. 0/8	2.1	6.1	105/150	6 cyclones, 990 ϕ	Wet scrubber
33 — 35	K 1 — K 3	Base 0/35					

Dust generation in the drums

When enumerating the factors which affect dust content in the waste gases of the drum, the sequence is quite immaterial. For all practical purposes, these factors act simultaneously and it is not immediately clear which are the more important ones. It is, however, certain that content increases with the quantity of finely granulated raw material entering the drum. This quantity is determined by its percentage in the starting material and in the mixture turned out, as well as by the extent of production. Furthermore, the type of rocks which crack when heated, are easily ground down by the motion of the drum and tend to form a great deal of dust. Finally, the excess air with which drums are operated plays a role. The quantity of waste gas is not only dependent on the material load of the drum, but also on the CO_2 content the equipment has been adjusted to.

There is no uniformity in the terminology concerning rocks and their granulations, raw material and the finished product. The operators refer to the finished product as bases, binder, and fine concrete, respectively. In the "Technical Specifications and Directives for the Construction of Bituminous Road Covers," the so-called "TV bit 3/64" issued by the Federal Ministry of Transport, Road Building Division, the following are distinguished:

TABLE 2. The granulation components of rocks in the mixture manufactured during the test (balance up to 100% is made up by filler and binder)

Plant	Type of rock	Granulation component
A	A 1, 4, 5 Moraine chippings, washed " " " " screenings, " Rhine sand	Fine asph. concr. 0/8 low chipp. cont. A 1, 4 high chipp. cont. A 5 5/8 = 10% = 30% 2/3 = 16% = 25% 0/3 = 32% = 15% 0/3 = 32% = 20%
	A 2, 3 Blast furnace slag chippings, washed " " " " " " " " screenings, " Rhine sand, "	Fine asph. concr. 0/8 5/8 = 10% 2/3 = 16% 0/3 = 32% 0/3 = 32%
B	B 2, 3 Blast furn. slag chippings, unwashed " " " screenings, " Rhine sand	Fine asph. concr. 0/8 high chipp. cont. 3/8 = 52% 0/3 = 33% 0/3 = 15%
	B 1 Gravel	Base 0/30 0/30 = 100%
C	C 1, 2 Basalt, unwashed " " Moraine, washed Rhine sand, "	Fine asph. concr. 0/8 high chipp. cont. 5/8 = 55% 2/3 = 25% 0/3 = 20%
D	D 1, 4 Basalt chippings, washed " " " " screenings + 15% natural sand (unwashed) Filler	Fine asph. concr. 0/8 high chipp. cont. 5/8 = 29% 2/3 = 28% 0,09/2 = 36% 0/0,09 = 7%
	D 2, 3 Basalt chippings " " " " " screenings + 15% nat. sand	Base 0/35 12/35 = 45% 8/12 = 11% 2/8 = 20% 0,09/2 = 21%
E	E 3 Basalt chippings, unwashed " " " " " " " screenings, " Rhine sand, "	Binder 0/12 8/12 = 20% 5/8 = 17% 2/3 = 18% 0,09/2 = 27% " = 10%
	E 1, 2, Basalt chippings, unwashed " " " " " " " screenings, " Rhine sand	Base 0/25 12/25 = 31% 8/12 = 12% 2/8 = 27% 0/2 = 13% 0/2
F	F 1, 3 Limestone chippings " " " screenings	Fine asphalt concr. 0/8 5/8 = 30% 2/5 = 30% 0/2 = 30%
	F 2, 4 Rhine gravel	Base 0/35 5/8 = 92%
G	G 2 Limestone chippings, washed " " " " screenings, unwashed	Fine asphalt concr. 0/8 5/8 = 45% 2/5 = — 0/3 = 45%
	G 1 Diabase chippings, washed " " " Limestone " " " screenings, unwashed	Binder 0/12 8/12 = 16% 5/8 = 17% 2/5 = 13% 0/3 = 40%
H	H 1, 2 Basalt chippings, washed " " " Limestone screenings, washed Natural sand	Fine asphalt concr. 0/8 5/8 = 27% 2/5 = 21% 0/2 = 29% 0/2 = 23%
	H 3, 4 Limestone chippings " " " " Rhine sand	Base 0/25 12/25 = 30% 8/12 = 20% 3/8 = 20% 0/2 = 30%
I	I 1, 2 Basalt chippings, washed " " " Limestone screenings, washed Blast furnace slag screenings	Fine asphalt concr. 0/8 5/8 = 25% 2/5 = 20% 0/2 = 24% 0/2 = 24%
	I 3, 4 Limestone chippings, washed " " " " " " Rhine sand	Binder 0/18 12/18 = 30% 5/12 = 20% 2/5 = 15% 0/2 = 30%
K	K 4 Limestone chippings " " Limestone screenings	Fine asphalt concr. 0/8 5/8 = 12% 2/5 = 23% 0/2 = 65%
	K 1, 2, 3. Limestone chippings " " " " Limestone screenings	Base 0/35 12/35 = 44% 8/12 = 25% 2/8 = 8% 0,09/2 = 16%

TABLE 3. Results of series investigation: 35 studies at 10 plants with standardized measuring program, identical instruments and personnel. Plant and raw material according to Tables 1 and 2.

Consec. No.	Plant No. and test No.	Drum capacity, t/hr	Upstr. of the dust collector: Gas quantity, 10^3 m³ STP/hr	Upstr. of the dust collector: Dust content g/m³	Upstr. of the dust collector: Dust content g/m³STP	Dust collector 1st stage (dry), downstream of the collector: Temperature, °C	Dust collector 1st stage (dry), downstream: Waste-gas quantity, 10^3 m³/hr	Dust collector 1st stage (dry), downstream: Dust content g/m³	Dust collector 1st stage (dry), downstream: Dust content g/m³STP	Dust collector 1st stage: Efficiency η, %	Collector 2nd stage (wet), downstr. of the collector: Waste-gas quantity, 10^3 m³/hr	Collector 2nd stage (wet), downstr.: Dust content g/m³	Collector 2nd stage (wet), downstr.: Dust content g/m³STP	Collector 2nd stage: Efficiency η, %	η 1st and 2nd stage, %	Upstream of the stack: Waste-gas temperature, °C	Upstream of the stack: CO_2 content, %	Upstream of the stack: Waste-gas quantity, 10^3 m³ STP/hr
1	A1	25	8.63	14.1	28.3	267	17.2	0.691	1.384	95.1	11.0	0.596	0.835	41.8	97.1	101	—	8.4
2	4	25	8.31	14.3	28.8	274	17.0	0.873	1.343	95.3	11.4	0.611	0.718	47.6	97.6	101	—	8.2
3	6	30	8.35	17.8	34.8	264	18.8	1.602	3.164	91.0	11.4	0.828	1.149	64.2	96.8	101	—	8.2
4	2	30	8.44	14.0	28.3	270	17.0	0.781	1.686	94.4	11.2	0.696	0.830	49.6	97.1	106	6.6	8.1
5	3	30	8.41	15.6	31.7	272	17.5	1.063	2.139	93.3	11.6	0.763	1.047	62.3	96.7	102	6.6	8.4
6	B2	60	22.2	79.6	123.8	149	34.6	1.76	2.73	97.8	nonexisting				97.8	149	3.2	22.1
7	2	64	22.2	65.8	131.6	145	34.5	2.27	3.63	97.4					97.4	145	3.0	22.2
8	1	70	21.2	32.7	63.1	142	34.4	0.916	1.465	97.2					97.2	162	3.3	21.2
9	C1	60	28.4	41.6	69.8	185	44.3	2.39	4.00	94.3	37.8	0.674	0.696	78.4	98.8	68	2.0	31.3
10	2	60	28.1	41.4	65.6	185	46.3	2.72	4.61	93.3	37.8	0.651	0.671	83.2	98.8	60	2.0	31.1
11	D1	60	30.8	26.0	33.4	87	48.8	3.23	4.38	87.1	46.4	0.140	0.182	86.4	98.4	47	1.0	37.8
12	2	55	35.2	35.0	116.6	46	41.6	12.8	16.2	87.0	46.1	0.591	0.707	85.1	98.4	37	1.1	38.8
13	2	60	32.6	21.6	28.8	78	46.2	4.90	6.76	77.3	46.7	0.207	0.256	95.8	99.1	47	1.1	37.8
14	3	60	34.7	17.2	23.3	72	46.9	3.76	6.00	78.2	46.0	0.188	0.203	95.6	99.0	41	0.8	37.0
15	E2	60	23.48	45.8	89.6	~100	Cooler a	41.0	60.0	37.6	48.7	0.083	0.112	99.8		82	2.3	38.0
16	1	60	20.83	66.7	83.7	"	dust-lad	44.0	60.1	36.4	48.8	0.072	0.093	99.8		87	3.1	36.2
17	2	60	20.22	63.0	73.4	"	sec. air	34.4	47.0	36.3	48.8	0.082	0.112	99.7		88	2.3	35.6
18	F1	80	22.8	60.9	78.8	160	31.8	—	—	—	28.8	0.137	0.166	—	99.8	67	2.2	24.7
19	2	70	17.4	76.6	118.1	160	22.0	0.10	9.44	82.1	26.2	0.224	0.277	96.3	99.7	66	5.2	21.4
20	2	70	16.6	33.4	62.0	160	26.8	3.12	4.61	90.8	23.3	0.136	0.166	96.0	99.6	63	4.4	18.5
21	4	70	17.3	27.6	43.1	164	23.2	2.47	3.88	91.1	26.2	0.171	0.207	93.2	99.4	68	4.3	21.6
22	G2	80	18.7	73.6	112.0	181	28.8	10.3	18.4	85.0	28.4	0.032	1.12	91.4	98.8	76	4.4	21.2
23	1	80	18.8	63.1	103.2	172	30.8	8.3	13.6	84.0	31.3	1.34	1.80	83.2	97.8	89	6.7	21.8
24	H1	36	14.76	19.8	28.4	81	22.7	3.11	2.81	89.4	20.2	0.260	0.314	88.8	98.8	66	3.1	16.7
25	2	35	15.04	19.8	26.2	87	21.2	1.20	2.26	91.4	20.0	0.284	0.318	86.7	98.7	66	3.3	18.8
26	3	46	18.06	20.8	26.7	83	21.1	3.68	4.43	82.8	20.8	0.432	0.607	88.0	97.8	47	2.8	17.8
27	4	46	17.60	23.1	29.8	80	22.8	4.05	5.33	82.4	22.4	0.637	0.830	87.1	97.7	63	3.1	18.8
28	J1	40	18.66	24.4	32.8	93	26.4	0.87	1.17	96.4	22.7	0.264	0.316	73.6	99.0	54	2.8	19.0
29	2	40	20.40	23.4	38.1	90	27.6	0.82	1.098	97.2	26.6	0.220	0.261	75.0	99.3	61	2.4	21.6
30	3	40	19.85	22.2	28.3	87	28.4	2.12	2.80	90.6	23.0	0.832	0.985	63.8	98.6	43	1.4	19.8
31	4	40	19.67	16.4	22.4	88	27.0	2.13	2.86	87.2	24.3	0.800	0.937	66.6	95.8	47	1.6	20.8
32	K4	75	30.7	78.4	111.2	108	42.0	3.08	4.31	96.1	41.8	0.049	0.077	98.4	99.8	63	3.8	34.4
33	1	128	25.2	87.9	103.2	182	42.1	4.78	7.97	95.1	34.6	0.072	0.090	98.6	99.8	73	8.7	27.6
34	2	134	27.6	83.2	160.7	221	49.7	4.64	8.33	94.4	41.1	0.082	0.100	98.6	99.8	78	10.6	33.3
35	3	128	27.4	81.6	180.2	208	47.7	4.47	7.02	95.2	37.1	0.058	0.071	99.0	99.8	78	10.1	29.4

(These Data Used in Tables 3-6 and 3-7)

1. asphalt binder
2. coarse asphaltic concrete
3. fine asphaltic concrete, low chippings content (20 — 35% chippings)
4. fine asphaltic concrete, high chippings content (35 — 65% chippings)
5. sand asphalt.

The following raw materials are processed:

Sand: i.e., mineral substances which pass the 2 mm-mesh screen and are retained by the 0.09 mm screen.

Chippings: i.e., crushed rock, sizes 2 — 25 mm.

Filler: i.e., mineral substances which pass the 0.09 mm mesh screen.

In these investigations the fine concrete had a particle structure of 0/8 mm, the binder 0/12 — 0/18 mm, and the bases 0/25 — 0/35 mm. These terms will be retained below.

Effect of the processed rock and its granulation

The fine particle component of the rock mixture to be dried, as adjusted for the prescribed particle structure of a given mixture, can be taken from the data of Table 2. If these values are correlated with the dust-content figures in Table 3, it is seen that the resulting Table 5 shows only a minor increase of dust content with rising fine particle component. This becomes understandable, when noting that the raw material as mentioned in Table 5 is washed.

The range of fine particles with a lower limit at zero cannot be assessed with certainty, since neither the proportion of the near-zero particles, nor their actual proximity to zero are known. However, if we separate the so-called filler, i.e., the proportion between zero and 0.09 mm from the fine range 0 — 2 mm (achieved by washing the sand), the granulation of the residue can once again be clearly defined. Measurements show that this granulation does not apparently have a greater share in dust formation than other coarser particulates. It makes no difference whether the material-mixture run through the drum is for the base, the binder, or the fine asphaltic concrete; dust content remains approximately equal if only washed material is used.

As can be seen from further evaluations, the assumed influence of rock type and of the granulations processed are of secondary importance, compared to the question as to whether the raw material is free of the smallest particles of the filler size, through having been fed either after washing, or else without addition of filler. Whether the latter procedure constitutes a genuine alternative to washing remains to be proved. The measured values for dust content in drum waste gases, which in Table 3 still appear as a confusing jumble, assume a clearly discernible order when separated according to whether washed or unwashed raw material was used (Table 6). The first column corresponds to the data from Table 5. In the third column, which represents unwashed material, a remarkable difference appears. The dust contents are all much higher and increase in ascending order, i.e., from "base" via "binder" to "fine concrete." Compared to these values, the dust content for washed material is almost insignificant. High dust-content values are therefore apparently associated with the use of unwashed raw material. A horizontal comparison of values in Table 6, with two measured values for half-washed material in the fine-concrete column is very interesting. The trend toward dust increase with rising fines is clearly recognizable.

If the high dust content of unwashed raw material is due to the finest, pulverulent particles, an identical or at least similar situation should logically occur, when a certain quantity of filler is added to washed raw material. This was investigated in the test series D1 and D4. The raw material of the high chippings content fine concrete had the following composition:

1. basalt chippings, washed	5/8 mm	: 29%
2. basalt chippings, washed	2/5 mm	: 26%
3. basalt chippings + 15% natural sand, unwashed	0.6/2 mm	: 20%
4. natural sand, unwashed	0.09/0.6 mm	: 18%
5. filler	0/0.09 mm	: 7%

In test D1, the last two materials, jointly constituting 25%, were only added to the mixture downstream of the drum. In test D4 they were present in the mixture from the beginning. If, for the sake of simplicity, we term them finest components, the following can be stated: dust content of drum waste gases when manufacturing fine concrete with partially washed raw material was

without finest component	33.4 g/m³ STP.
with finest component	116.5 g/m³ STP.

In fact, this relation attains the same order of magnitude as that resulting for washed and unwashed starting material. If the filler is added to the drum, the dust content of the drum waste gases can thus be compared with that arising for unwashed starting material.

Measured values related to the type of rock used appear in Table 7. The following materials were used for the comparison:

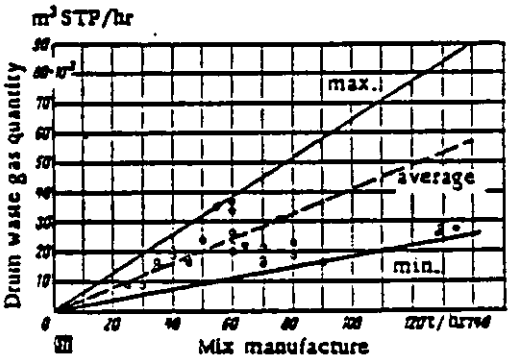


Figure 1. Waste-gas quantity of the drying drums as a function of mix production

TABLE 4. Results of emission measurements; 83 studies in 27 installations, carried out at the behest of the supervisory authorities by various institutes with differing measuring instruments

Consec. No.	Plant No. and test No.	Mixture manufactured	Drum capacity, t/hr	Upstream of the dust collector: Waste-gas quantity, 10^3 m³ STP/hr	Dust content: g/m³	Dust content: g/m³ STP	Temperature, °C	CO_2 content, %	Dust collector 1st stage (dry): downstr. of the collector: Temperature, °C	Waste-gas quantity, 10^3 m³/hr	Dust content: g/m³	Dust content: g/m³ STP	Efficiency η, %	Dust collector 2nd stage (wet): downstr. of the collector: Waste-gas quantity, 10^3 m³/hr	Dust content: g/m³	Dust content: g/m³ STP	Efficiency η, %	1st and 2nd stage, %	Upstream of the stack: Waste-gas temperature, °C	CO_2 content, %	Waste gas quantity, 10^3 m³ STP/hr
36	KL1	Base 0/35 gravel	30	10.4					140	15.9	1.35	2.05		13.6	0.094	0.116	94.1		61	4.2	11.1
37	2	" " "	32	11.0					138	16.7	1.22	1.84		14.2	0.116	0.142	91.9		69	3.9	11.7
38	KM1	Base 0/35 gravel	20	10.3	6.21	6.78				13.4	0.933	1.065	82.1	nonexisting					77		
39	2	" " "	20	9.7	6.65	7.64				13.3	0.869	1.192	84.4						97		
40	KN1	Base 0/35 basalt	16	2.0					299	4.2	0.764	1.681		nonexisting					299		
41	2	" " "	16	2.2					260	4.2	0.903	1.731							260		
42	KO1	Base 0/35 gravel	63	16.7	20.7	37.9			229	28.7	1.87	3.43	91.0	22.4	0.348	0.462	83.0	98.7	87	5.8	16.9
43	2	" " "	66	16.6	19.6	35.1			220	27.7	1.77	3.18	91.0	22.1	0.234	0.307	89.4	99.0	84	6.1	16.8
44	KP1	Base 0/25	30(60%)	25.1	23.5	28.2				30.3	4.73	5.70	79.8	nonexisting					53	0.8	25.1
45	2	" "	30(50%)	24.6	12.8	16.7				30.3	3.52	4.37	72.4						60	1.2	24.6
46	KQ1	Fine asph. concr. 0/8	57			29.3						3.18	89.0	37.8	0.184	0.243	91.8	99.1	86	2.1	26.6
47	KR1	Base 0/35 gravel	38	12.2	4.49	7.2			170	18.6	0.91	1.265	82.4	nonexisting					170		
48	2	" " "	40	12.1	6.97	9.65			172	18.3	1.127	1.809	81.1						172		
49	KS1	Base 0/35 gravel	45	14.0	14.4	27.4			246	26.6	2.38	4.47	83.7	nonexisting					246		14.0
50	2	" " "	45	14.1	10.0	18.9			238	26.6	1.13	2.11	88.7						238		14.1
51	KT1	Base 0/35 gravel	45	12.6	10.13	14.99			170	20.3	0.594	0.878	94.1	18.5	0.281	0.415	52.7	97.1	129		12.6
52	2	" " "	50	13.4	14.70	21.46			163	21.4	0.793	1.158	94.1	19.5	0.440	0.643	44.6	96.9	124		13.4
53	KU1	Base 0/35 gravel	43	11.9			255	5.8	200	22.0				16.6	0.605	0.813			74	5.1	12.3
54	2	" " "	41	11.9			246	4.7	191	21.7				16.4	0.685	0.895			68	4.4	12.4
55	KV1	Base 0/35 gravel	10	12.2						15.2	0.22	0.278		nonexisting					65	0.6	12.2
56	2	Fine asph. concr. 0/8	85	11.9						14.7	0.447	0.552							66	0.4	11.9
57	KW1	Base 0/35 gravel	34	14.6					85	19.8				17.8	0.057	0.070			56	1.9	14.4
58	2	" " "	34	14.9					92	20.3				18.3	0.058	0.072			66	2.2	14.8
59	KX1	Base 0/35 gravel	80	28.5					194	49.1				38.8	0.194	0.258			83	4.3	29.1
60	2	" " "	80	30.3					170	60.0				38.8	0.199	0.268			88	4.8	29.1
61	KY1	F. asph. concr. 0/8 grv	28	11.2					83	15.2					0.262	0.314			48	2.0	
62	2	Base 0/35 gravel	30	10.2					118	15.1					0.131	0.151			67	3.6	
63	3	Binder 0/25 gravel	30	16.6					65	19.6					0.083	0.101			42	2.6	
64	4	" " "	30	17.0					90	22.8					0.112	0.132			48	2.6	
65	KWL1	Fine asph. concr. 0/8	40											16.4	0.160	0.210			108	5.9	11.0
66	2	" " (moraine)	40											16.4	0.128	0.180			110	6.9	11.0
67	KWM1	Base 0/35 gravel	60											21.6	0.062	0.075			66	3.8	17.9
68	2	" " "	60											21.6	0.106	0.128			66	3.6	17.9

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69	HML 1	Fine asph. concr. 0/8	40	13.1						18.7	7.41	10.68		nonexisting					117	1.8	13.1
70	2	Binder 0/15	40	11.6						18.7	2.85	4.60							168	4.0	11.6
71	HMM 1	" 0/12	28	8.1						17.4	6.9	14.9							318	7.2	8.1
72	2	Mixture 0/8	36	8.1						17.1	10.6	19.6							239	4.2	8.1
73	3	Fine asph. concr. 0/6	35	9.6						17.2	14.44	26.0							220	3.4	9.6
74	HMN 1	Fine asph. concr. 0/2	61(60%)	63.5						67.1	1.34	1.68							70	1.8	63.5
75	2	Binder 0/25	120											34.8	0.492	0.584	dry special		49	5.8	29.4
76	HMO 1	Fine asph. concr. 0/8	42											26.9	0.304	0.413			94	3.8	19.4
77	2	" " " "	40											25.3	0.663	0.914			101	6.0	18.4
78	3	" " " "	43											24.6	0.624	0.890			118	6.4	17.3
79	4	" " " "	44											23.4	0.748	1.00			110	4.5	16.5
80	HNL 1	Binder 0/15	47	19.3	24.4		126		82	26.2	1.68		83.7							1 to 3	19.1
81	2	" "	63	20.7	27.7		118		86	27.1	2.04		80.4							"	20.3
82	3	Fine gravel 0/3	72	20.0	187.0		122		112	25.8	26.6		86.7							"	18.9
83	4	" " "	48	20.0	163.0		122		102	26.0	20.4		86.2							"	19.2
84	5	Binder 0/18	46						101	28.6	3.62			20.8	0.83		80.7		31	"	19.3
85	6	Fine gravel 0/3	78						81	25.7	18.2			21.7	2.01		80.7		33	"	18.8
86	7	" "	65						94	19.3	14.3			20.6	2.73		88.2		33	"	18.2
87	8	" "	68						73	25.5	18.6			23.9	1.88		81.3		29	"	20.3
88	HNM 1	Base 3/25	60											24.4	0.18	0.222			63	3.6	19.8
89	3	" "	60											24.2	0.207	0.259			68	"	19.4
90	2	Fine asph. concr. 0/8	60											24.6	0.615	0.770			67	"	19.6
91	4	" " " "	60											25.0	0.204	0.260			75	"	19.6
92	HNN 1	Base 0/25	10											5.4	0.279	0.330			47	1 to 2	4.5
93	2	" "	10											5.4	0.223	0.260			42	"	4.6
94	3	" "	10											3.2	0.663	0.810			102	"	2.3
95	StL 1	Fine asph. concr. 0/2	40.6	12.3		102.4	243	6.1				6.1	83.6			2.0	38.4	96.1	125		24.6
96	2	" "	43.6	11.9		96.6	237	6.1				6.2	92.9			2.8	16.2	94.3	122		24.5
97	3	" "	42.5	11.9	96.6	96.6	237	6.1				5.8	93.4			2.3	25.0	26.0	123		24.6
98	4	" "	45	11.0		65.4	264	6.4				5.3	91.0			1.7	39.8	94.6	130		23.7
99	5	" "	40	11.9		102.0	236	6.7				5.8	94.1			2.5	12.8	94.8	117		24.7
100	6	" "	43	11.6		146.0	237	6.2				8.0	94.3			3.4	13.0	95.0	116		24.8
101	StM 1	Binder 0/2 diabase	95	17.6		87.6	187	4.1								0.355		99.6	60		21.8
102	2	" " "	92	17.6		86.3	187	4.0								0.359		99.6	60		21.8
103	3	Fine asph. concr. 0/8 diabase	73	17.1		61.6	196	3.7								0.381		99.4	60		21.8
104	4	Base 0/35 limestone	93	18.8		64.0	188	3.2				5.8	91.0			0.353	93.9	99.4	66		20.9
105	5	" " "	107	18.3		76.0	214	3.6				5.1	93.2			0.361	93.1	99.6	68		20.8
106	6	" " "	94	18.3		64.0	200	3.7				6.0	90.7			0.346	94.2	99.6	60		20.8
107	7	" " "	88	18.2		61.2	204	3.4				5.0	91.7			0.320	93.7	99.6	68		20.8
108	StN 1	Base 0/35 gravel	75					4.9								0.124		99.0	62		19.3
109	2	" " "	75					4.7								0.137		99.2	65		20.7
110	3	" " "	76					4.2								0.096		78.8	64		20.7
111	4	" 0/25 "	66					3.1								0.167		98.8	63		21.5
112	5	" " "	66					1.6								0.163		99.1	60		21.6
113	EL 1	Fine asph. concr. 0/8	65	Cold proc.					70					31.6	0.301	0.369			52		26.6
114	2	" " " "	65	"					80					31.7	0.418	0.494			50		26.8
115	3	" " " "	65	"					80					31.8	0.298	0.355			52		26.6
116	4	Binder 0/12	60						116					31.8	0.514	0.612			52		26.8
117	5	Base 0/35	60						160					32.2	0.376	0.452			56		26.9
118	6	" 12/25	65						60					31.3	0.140	0.160			40		27.2

TABLE 5. Effect of the particle components 0 — 2 mm on dust content

Mixture manufactured	Fine asphaltic concrete		Binder	Base
	low chipp. cont.	high chipp. cont.		
Classification (mm)	0/8	0/8	0/12 to 0/18	0/25 to 0/35
Particle sizes < 2 mm raw material (%)	64 to 63	48 to 30	40 to 30	30 to 19
Dust content for washed raw material (g/m^3 STP)	39.1 to 28.2		29.3 to 22.4	29.9 to 23.3

TABLE 6. Measured dust content in the drum waste gases for washed and unwashed raw material

Dust content Measured values from — to		Washed		Half-washed		Unwashed	
		(g/m^3 STP)		(g/m^3 STP)		(g/m^3 STP)	
		Min.	Max.	Min.	Max.	Min.	Max.
Fine asphaltic concrete	0/8	28.2	39.1	69.5	69.9	117.0	163.0
Binder	0/12	—	—	—	—	89.5	103.2
	0/18	22.4	29.3	—	—	—	—
Base	0/25	—	—	—	—	72.4	93.7
	0/30	—	—	—	—	53.1	—
	0/35	23.3	29.9	—	—	43.1	52.0

TABLE 7. Effect of rock type on dust content

	Raw material, washed			
	Proportion 0 — 2 mm %	%	Type of rock (in proportion of dust content)	Dust content g/m^3 STP
Fine asphaltic concrete 0/8 low chippings content	64	32	Moraine, screenings	28.3 to 28.6
		32	Rhine sand	
Fine asphaltic concrete 0/8 low chippings content	64	32	Blast furnace slag, screenings	28.3 to 31.7
		32	Rhine sand	
Fine asphaltic concrete 0/8 high chippings content	35	15	Moraine, screenings	35.9
		20	Rhine sand	
Fine asphaltic concrete 0/8 high chippings content	52	29	Limestone, screenings	28.2 to 28.4
		23	Natural sand	
Fine asphaltic concrete 0/8 high chippings content	48	24	Limestone, screenings	32.8 to 39.1
		24	Blast furnace slag, screenings	
Binder 0/18	30	30	Rhine sand	22.4 to 29.3
Base 0/35	21	21	Basalt, screenings, with 1/4 natural sand	23.3 to 29.9

Basalt, blast furnace slag, limestone, moraine, natural sand, limestone.

To eliminate interference by secondary effects, washed raw material was once again used as a base. Despite widely differing proportions of the fine-granulate range from 0 — 2 mm in the starting material, the measured dust contents scarcely deviate. This means not only that, in this respect, the differences between the rock types themselves are small, but also that, in the absolute sense, their additional effect on dust generation is quite insignificant. This could also be a confirmation of the identical suitability of these rocks.

The material load of the drum

The drum dimensions of the ten plants studied in the program are known, as is their performance during measurement. The rated capacities in Table 1 are based on data supplied by operators. Lower numerical values represent capacity when making fine concrete.

It was not intended to investigate the internal processes occurring in the drums. However, one may consider that material charging creates a sort of area load in the drum. Since the latter turns continuously, it is the tipping process which must be made responsible for dust generation. The quantity of material, the speed, the height of fall and the path length probably play a role.

In this study the drums were charged approximately as follows:

	Material load related to	
	projected area of the drum, t/hr · m²	drum cross section, t/hr · m²
During the manufacture of binder or base		
average	4.7	27.0
maximum	10.4	49.0
minimum	2.5	15.7
During the manufacture of fine asphaltic concrete		
average	3.4	22.0
maximum	5.8	49.0
minimum	2.2	12.5

The different factors will have to be investigated in further, special investigations. Due to the great influence of unwashed raw material on dust content, the available number of truly comparable measured values is inadequate. To give one example: in the mean load range of fine-concrete manufacture from washed material dust content was 26 — 39 g/m³ STP. In one test series, however, dust content lay approximately between these two values, despite a material load which was twice as big.

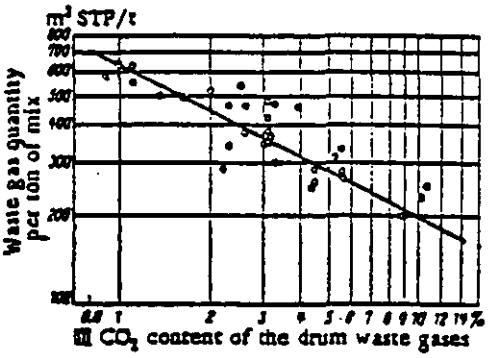

Figure 2. Specific waste gas quantity per ton of mix as a function of CO_2 content of the drum waste gases

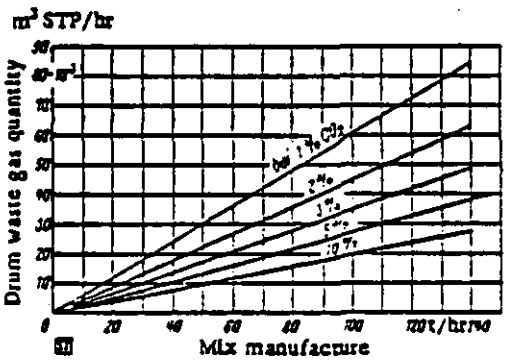

Figure 3. Waste gas quantity of the drying drum as a function of excess air

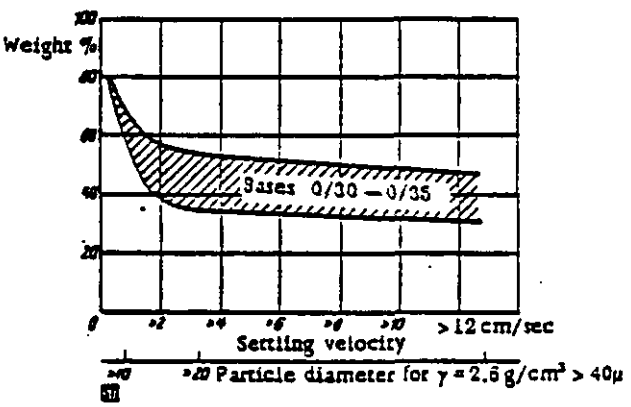

Figure 4. Particle size distribution of dust in the manufacture of bases 0/30 — 0/35 mm

The waste gas load of the drum

It is also important to relate the measured quantities of waste gases in the drum to the quantity of material processed. If gas quantities are plotted vs. production, we obtain Figure 1, which shows a considerable scattering of measured values. A mean relation is indicated by the two limiting lines, and may by useful for rough calculations. However, the question remains of whether a cause for the considerable scattering can be seen from the measured results. The CO_2 content which was also measured, and which could conceivably serve as a measure [of the material load/waste gas relation], was found to differ greatly.

The drying process in the drums is sustained by combustion. Excess air is calculated from the measured CO_2 content and the theoretical k_{max} value which, for the commonly used light fuel oil EL, can be set at approximately 16%. Upon calculation, excess air is found shockingly high. However, it must be regarded solely in connection with the specific working process, namely drying and heating of the material for subsequent bituminization.

Excess air simultaneously serves for cooling and for protection against an impermissibly high heating of the material. Nevertheless, in average installations, excess air quantities can sometimes reach ten times the values of some very good modern units, of which one was also included in the test program.

If the waste-gas quantity is divided by the quantities of the manufactured mix, the effect of the varying CO_2 contents is illustrated quite clearly (Figure 2). The specific waste-gas quantities were: in low-efficiency units (1% CO_2), about 600 m^3 STP/th; in average units (3% CO_2), 300 — 400 m^3 STP/th, and in the best units (10% CO_2), about 200 m^3 STP/th. Differences in the quantity of waste gases are thus not only due to differing production volumes, but mainly to the mode of operation of the drum. This realization is significant for conclusions to be drawn later.

Figure 1 can be complemented by lines for which CO_2 content is the parameter. These then indicate the waste-gas quantities for which, in the individual case, waste-gas ducts, dust collectors, suction fan and stack would have to be calculated (Figure 3).

Particle sizes of dusts

The dust samples collected during measurement were subsequently analyzed for particle size using Gonell classifiers. In accordance with VDI Directive 2031 "Fineness Determination of Technical Dust," the dusts were classified according to their settling velocities in steps from 0.2 to 25.6 cm/sec. Specific weight (density or apparent density) was determined by the pyknometric method. This permits conversion of the settling velocity to particle size by means of the aforementioned directive.

The results of air classification are given in Table 9. Scattering is great, and it is not easy to tell the significant from

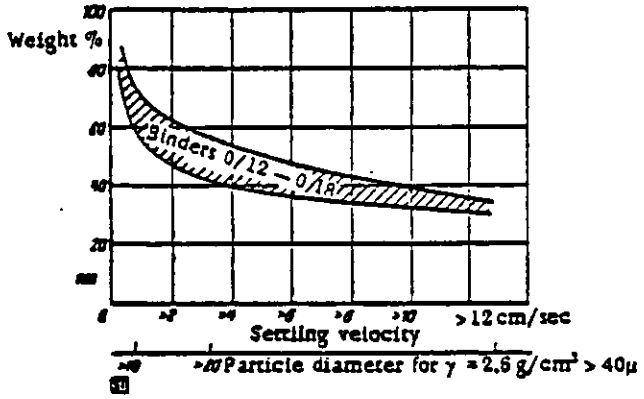

Figure 5. Particle size distribution of dust in the manufacture of binders 0/12 — 0/18 mm

the nonsignificant values. The uncertainties are created by the fact that the values of the dust samples at the drum outlet must partly be formed from the percentual summation of separated dust and clean-gas dust of the first collector stage. As is known, the taking of a representative average sample from a great quantity of separated dust is difficult.

Plotting the particle lines produces a confusing multitude of curves. However, since these are residue curves (for definition see VDI 2031), the extremely high curves can be neglected as less important for subsequent dust removal. The problem is not how coarse, but how fine the dust is. The residue curves for fine dust, however, lie lower.

As shown in Figures 4, 5, and 6, the particulates of the other dusts are practically all in a range which, for an apparent density of 2.6 g/cm^3, can be given approximately as follows:

Residue

> 10μ: 55 to 78%
> 20μ: 35 to 65%
> 40μ: 28 to 54%

Passage

> 10μ: 45 to 22%
> 20μ: 65 to 35%
> 40μ: 72 to 46%

In case of these large intervals, usually quite adequate in practice, the numerical data apply both to the dust during the manufacture of bases and binders, and to fine concrete. With the latter, this is not quite true for washed starting material, the dusts from which contain less fine components, as is evident from Figure 6.

Dust removal

The dust content of drum waste gases is occasionally so great that the waste-gas flow is held to be comparable to pneumatic dust conveying and dust removal to separators used with such conveyers. Such comparisons do not apply to our measured values, showing maximum dust contents of 160 g/m^3 STP. Average dust emission of the drums for

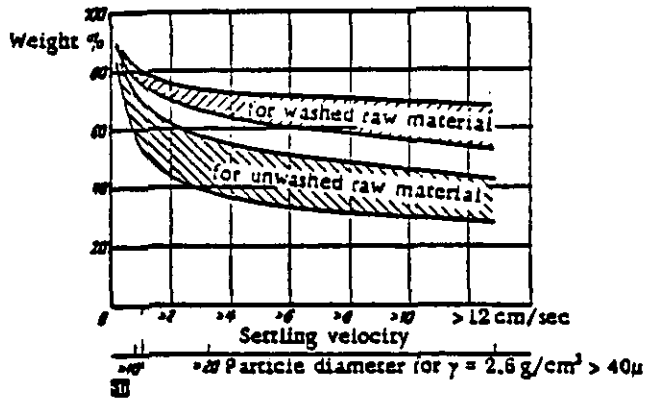

Figure 6. Particle size distribution of dust downstream of the drum in the manufacture of fine asphaltic concrete 0/8 mm

35 measurements at 10 installations is 23 kg of dust per ton of mixed material, i.e., 2.3%. The lowest value was 0.9% and the highest, 7.5%.

While, in the past, plants were exclusively equipped with centrifugal collectors, modern plants are provided almost only with two-stage dust removal. Cyclones serve as preseparators in the first stage, the second stage being frequently a wet scrubber, fabric or bulk layer filters being also used increasingly, as are sometimes special electrostatic precipitators.

Of the 10 units in the test program, 8 were equipped with two-stage dry-wet collectors. The number and dimensions of available cyclones can be seen in Table 1. One installation had only a fabric filter with preliminary surface cooler, and one was only equipped with a relatively large number of medium-size cyclones. The efficiencies measured at the plants are given in Table 3, separately for each stage and altogether for the entire dust removal unit. Referring to the 10 plants investigated, the following can be concluded:

1. Cyclones of the first stage

No. of plants	Efficiency (%) (temporary)
4	> 95
2	> 90
3	> 85
1 (without cyclone)	—

2. Wet scrubbers of the second stage

No. of plants	Efficiency (%) (temporary)
1	> 98
2	> 95
1	> 90
2	> 85
1	> 70
1	> 50
2 (without wet scrubber)	—

3. Both stages together

No. of plants	Efficiency (%) (temporary)
1	99.9
1	> 99.5
2	> 99.0
1	> 98.5
2	> 98.0
1	> 97.5
8 cyclones + wet scrubbers 1 fabric filter	> 99.5
1 with cyclones only	> 97.0

As can be seen, dust removal in all 10 plants was quite satisfactory. However, it should be noted that the test program did not include the very worst plants. The differences between very good and merely good dust removal become only obvious and, in fact, striking, when clean gas dust content after the second stage is examined (in Table 3). An efficiency for the entire installation of less than 99% no longer appears so exemplary. However, this is already in anticipation of the recommendations of the recent Emission Directive VDI 2283 for new plants reported elsewhere.

The reliability of cyclone collectors is generally recognized. Although their efficiency has a natural limit when the particles become too small, it is quite sufficient for many practical tasks. Cyclones must have specific dimensions and be subjected to the correct load. The manufacturers guarantee graded efficiencies for their cyclones, often formulated as follows for known dusts in known situations:

Particle sizes (μ)	Efficiency (%)
0 to 10	70
10 to 20	95
20 to 40	98
above 40	99

Apart from uncertainty for the lowest particle sizes, the validity of these data was repeatedly confirmed in innumerable acceptance tests. If these data are assumed as given also in this case — the high density of dust particles according to VDI 2031 of an average 2.6 g/cm³ favors such an assumption — they can be used to establish evaluation factors to assess the efficiency of these collectors.

In Table 9 the total efficiencies, as actually measured at the cyclones, are related to the theoretically possible by means of the particle analyses in Table 8. It is seen that in 11 of 17 analyzed investigations the calculated values were at times exceeded in practice. Also, the effect of particle size in the individual stages on the final result is clear. The average of the theoretically possible total efficiency is 91.2%, the lowest value is 86% and the highest, 97.7%. Among measured values the average is 91.4%; the lowest, 77.3% and the

TABLE 8. Particle analysis of the dust samples in the test program

Dust in the drum waste gases	Plant No.	Raw material	Raw gas dust content, g/m³ STP	CO_2 %	Waste gases per t/hr m³ STP/t/hr	Density, g/cm³	Raw gas dust in the drum waste gases Particle size distribution by settling velocity intervals Weight proportion in %, settling velocities in cm/sec								
							< 0.2	< 0.4	< 0.8	< 1.6	< 3.2	< 6.4	< 12.8	< 25.6	< 25.6
1. For washed raw material in the manufacture of															
1.1 Fine asphaltic concrete 0/8	A4	Moraine + Rhine sand	28.6	4.5	330	2.4	10.5	16.7	23.2	28.6	34.3	39.7	46.0	57.1	42.9
	~~A8~~	~~Blast furnace slag + Rhine sand~~	~~86.9~~	~~6.6~~	~~980~~	~~2.4~~	~~11.0~~	~~16.7~~	~~22.4~~	~~27.0~~	~~32.2~~	~~38.5~~	~~46.9~~	~~61.3~~	~~38.7~~
	D1	Basalt + natural sand	33.4	1.0	630	2.6	7.0	13.1	18.2	22.8	26.7	28.3	32.0	38.2	61.8
	H2	Basalt + lime + natural sand	26.2	3.3	470	2.6	8.7	17.0	23.4	27.6	33.4	36.2	45.9	59.1	40.9
	12	Basalt + lime + blast furnace slag	39.1	2.5	540	2.9	10.8	14.0	17.2	25.1	34.5	38.5	47.2	64.1	35.9
1.2 Binder 0/18	13	Lime + Rhine sand	29.3	1.4	500	2.7	13.7	29.1	40.9	49.2	58.1	64.7	70.2	80.9	19.1
1.3 Base 0/35	D2	Basalt + natural sand	29.9	1.1	630	2.9	15.1	25.0	41.1	58.1	65.4	67.0	69.1	73.3	26.7
2. For half-washed raw material in the manufacture of															
2.1 Fine asphaltic concrete 0/8	C1	Basalt + moraine + Rhine sand	69.9	2.0	520	2.5	6.9	13.8	22.0	29.6	37.2	45.9	54.7	74.1	25.9
	C2		69.5	2.0	520	2.5	7.8	16.9	24.9	31.7	37.4	42.6	50.9	58.9	41.1
3. For unwashed raw material in the manufacture of															
3.1 Fine asphaltic concrete 0/8	B3	Blast furnace slag + Rhine sand	133.5	3.0	350	2.6	4.2	7.7	12.5	18.3	25.4	32.7	41.4	56.7	43.3
	D4	Basalt	116.5	1.1	640	2.8	15.9	26.8	41.5	53.8	61.5	67.6	72.0	80.6	19.4
	F3	Limestone	119.1	5.2	310	2.4	11.0	19.8	27.7	35.5	43.2	48.9	57.6	66.9	33.1
	G2	Limestone	117.0	4.4	260	2.5	8.3	20.1	37.0	50.2	59.6	66.7	72.1	82.5	17.5
	K4	Limestone	111.2	3.9	460	2.7	1.5	2.1	2.9	3.8	4.6	6.3	10.5	16.3	83.7
3.2 Binder 0/12	G1	Diabase + lime	103.2	5.7	270	2.5	5.9	16.5	29.1	35.1	43.8	53.9	66.0	81.9	18.1
3.3 Base 0/30	B1	Gravel	53.1	3.3	300	2.5	3.6	5.1	7.0	8.9	10.9	12.8	16.3	23.7	76.3
Base 0/35	F2	Rhine gravel	52.0	4.4	280	2.6	16.5	24.0	32.5	41.5	45.6	48.5	53.0	60.4	39.6

(THESE DATA REPRODUCED IN TABLE 3-6)

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highest, 97.4%. Mean and maximum of the measured total efficiency just about equal the mean and maximum of the theoretically possible.

Wet scrubbers as a second stage are widely used because of their applicability also for fine dusts in the clean gas of the cyclones, and because of their simple design and operation. Particle size is less decisive to attainable efficiency than the wettability of the dust and the degree of probability with which the particles can be brought into contact with water. The simplicity of design can easily disguise these true difficulties.

Thus not all wet scrubbers can be regarded as truly efficient. It is not enough to spray water through nozzles into a dust-laden gaseous flow. Neither is it sufficient to wet the inner walls and partitions of the collector with water. Too many particles never reach the walls. It is now known that the required large surface at which contact can take place can only be achieved by means of innumerable ultrafine water droplets. To generate the latter, power is needed which is provided either by special pumps and blowers from the outside, or taken from the suction draft fans. In both cases this involves a correspondingly high pressure loss.

In tests with different wet scrubbers the following relationships were established:

Type of scrubber	Resistance, measured (mm WG)	Efficiency, measured (%)
1. Only spraying nozzles, self-made by plant	(20)	42 to 64
2. Container with attachments and water bath, manufacturer A	100	79 to 83
3. The same, manufacturer B	135	64 to 75
4. Rotating gas scrubber, self-made by plant	155	86 to 89
5. Special type, manufacturer C	140 to 180	95 to 96
6. The same, manufacturer D	250	93 to 96
7. Injection of water into constriction of gas flow	210 to 315	98 to 99
8. Special type, manufacturer E	340 to 360	83 to 91

Efficiencies are really good only in plants 5, 6, and 7. The special type 5 reached its efficiency at the most favorable resistance and type 6 required a considerably higher resistance for the same results. Type 7 with a still greater effort reached the best efficiencies of all plants studied. Type 8 did not attain these values in spite of increased resistance.

The fabric filter in one of the 10 plants investigated confirmed the good properties this dust-removal system is known to possess. At a resistance of 130 mm WG it reaches the highest efficiencies of 99.7 and 99.8%. The conditioning of waste gases upstream of the filter for protection against excessively high or low temperatures requires careful planning and maintenance. If these are secured, nothing prevents the use of such filters, also of types with layered material. In the case at hand, this fabric filter was operated at a raw gas dust load of 47 – 60 g/m³ STP, since in the preliminary surface cooler some 35% of the dust from the drum was already eliminated. At the time of the measurements the preparation plant had a drum gas dust content of 72 – 94 g/m³ STP. At higher dust contents the use of a more effective first-stage collector is therefore necessary.

Conclusions

In regard to its quantity and particle size the dust in the waste gases of the drum extends through a wide range. To be more specific, three groups are seen for dust content, largely determined by whether the starting material is washed, unwashed, or processed in mixed components.

1. Completely washed raw material causes the lowest dust content. Values between 22 and 39 g/m³ STP were found. Dust contents encountered when washing base and binder material were approximately in the lower half of this range, with 22 – 30 g/m³ STP, and somewhat higher for fine concrete with 26 – 39 g/m³ STP. Compared to the mean of about 30 g/m³ STP, these differences are practically insignificant.

2. In processing partly washed and partly unwashed raw material, dust contents measured during the manufacture of fine concrete were about 70 g/m³ STP.

3. Unwashed raw material causes maximum dust levels in waste gases for all types of mix. Dust content rises sharply with a growing proportion of fine particles in the materials for base, binder, and fine concrete manufacture. The measured dust contents in bases 0/35 – 0/25 were between 43 and 94 g/m³ STP, for binder 0/12 between 90 and 103 g/m³ STP and for fine concrete 0/8 between 117 and 163 g/m³ STP.

For the particle sizes of these dusts the following distribution can be given:

Particle sizes intervals (μ)	Weight %
0 to 10	46 to 22
10 to 20	20 to 13
20 to 40	7 to 11
> 40	28 to 54

Deviations were only observed towards the coarser range. The density of the dust particles according to VDI 2031 was, in the average, about 2.6 g/cm³.

Given the capacities of modern cyclone collectors it can be expected that some 85 – 92% of the dust of this composition

(These Data Used in Table 3-7)

TABLE 9. Comparison of the measured efficiencies of cyclones, installed as preseparators at the time of the tests, with the efficiencies theoretically attainable according to the guarantees of the manufacturers

Plant No.	Dust proportion in particle-size intervals (ϱ = 2.8 g/cm³) 0 to 10µ %	10 to 20µ %	20 to 40µ %	> 40 µ %	Total efficiency cyclone measured %	Graded efficiency guaranteed by manufacturer 0 to 10µ %	10 to 20µ %	20 to 40µ %	> 40 µ %	Total efficiency calculated according to these guarantees 0 to 10µ %	10 to 20µ %	20 to 40µ %	> 40 µ %	Total %	Deviation in % (measured — guaranteed) +	—
A4	23.2	11.1	11.7	54.0	95.4	70%	95%	98%	99%	16.2	10.6	11.5	53.5	91.8	+ 3.5	
3	22.4	9.8	14.7	53.1	93.3					15.8	9.3	14.4	52.6	92.1	+ 1.2	
D1	18.2	8.5	5.3	68.0	87.1					12.7	8.1	5.2	67.4	93.4		— 6.3
H2	23.4	10.0	12.5	54.1	91.3					16.4	9.5	12.3	53.5	91.7		— 0.4
J2	17.2	17.3	12.7	52.8	97.2					12.0	16.5	12.4	52.4	93.3	+ 3.9	
J3	40.9	17.2	12.1	29.8	90.5					28.6	16.3	11.9	29.6	86.4	+ 4.1	
D2	41.1	24.3	3.7	30.9	77.3					28.6	23.1	3.6	30.6	86.1		— 8.8
C1	22.0	15.2	17.5	45.3	94.3					15.4	14.4	17.2	44.8	91.8	+ 2.5	
2	24.9	12.5	13.5	48.3	93.3					17.4	11.9	13.3	48.6	91.2	+ 2.1	
B3	12.5	12.9	18.0	58.6	97.4					8.8	12.2	15.7	58.0	94.7	+ 2.7	
D4	41.5	20.0	10.5	28.0	87.0					29.0	19.0	10.3	27.7	86.0	+ 1.0	
F3	27.7	15.5	14.4	42.4	92.1					19.4	14.7	14.1	41.9	90.1	+ 2.0	
G2	37.0	22.6	12.5	27.9	85.9					25.8	21.5	12.3	27.6	87.2		— 1.3
K4	2.9	1.7	5.9	89.5	96.1					2.0	1.6	5.8	88.5	97.7		— 1.8
G1	29.1	14.7	22.2	34.0	86.9					20.4	14.0	21.8	33.6	89.8		— 2.9
B1	7.0	3.9	5.4	83.7	97.2					4.9	3.7	5.3	83.0	96.9	+ 0.3	
F2	32.5	13.1	7.4	47.0	90.8					22.7	12.5	7.3	46.5	89.0	+ 1.8	

will be retained in the first stage. Efficiency increases with increasing coarse components up to a possible 95%.. Since, furthermore, the dusts are relatively heavy and the guaranteed data of the manufacturer mostly refer to densities of only 2 g/cm³, given the high dust contents, the higher efficiencies are certainly attainable.

In good wet scrubbers, such as are frequently used as a second stage, residual dust from the first stage is separated with efficiencies of 95 — 96%, in special cases even up to 98 — 99%.

Fabric or bulk layer filters used instead of wet scrubbers can attain efficiencies above 99%, when properly secured against unsuitable waste gas conditions.

The present situation with regard to dust removal in preparation plants is thus largely clear. A detailed investigation of the processes of dust generation, though beyond the framework of this article, would be of great interest for the further development of preparation plants, concerning problems of dust load and its removal.

For particles of about 10 and 20µ the settling velocities are only 0.8 and 3.2 cm/sec. Even coarser particles of 40µ settle only at some 12.8 cm/sec. Being stirred up by tipping processes in the drums, such particles are easily emitted with the gases. The drag of waste gases is still so great that 55 — 70%, and sometimes even up to 90% of all dust particles in the waste gases are larger than 40µ.

Given the tendency towards economical maximum performance, the future will hardly bring larger drums for the same capacities. Consequently, dusts capable of being airborne will continue to leave the drums, unless waste gas quantities can be greatly reduced. This is possible. Even if specific dust content is to remain equal (in test series K of the programs this was the case, in spite of 10% CO_2), a reduction of excess air to the limit of the possible could lead to further improvement of dust removal. The smaller waste gas quantities could permit the use of specifically more expensive types of collectors at the same cost. It is possible that development will move in this direction, and that no reasons for controversy will remain also concerning the very last residues of dust in waste gases emitted by the stacks.

Bibliography

1. Walter, E. Causes of the Dust Situation at Mixing Plants for Bituminous Road Building Materials and Measures for Improvement. — Strassenbau, 57th year of publ., No. 5, pp. 297–305. 1966.
2. Walter, E. The Dust Situation at Mixing Plants for Bituminous Road Building Materials in the German Federal Republic. — Staub-Reinhalt. Luft, Vol. 26, No. 11, pp. 34–41. 1966 [English translation].

Summary

Dust in waste gas from preparation plants for road building depends on many characteristic factors. This is valid for the dust at the drying drum outlet and also for clean gas dust at the chimney inlet. The crude gas dust is naturally influenced by the properties of raw material, whilst clean gas dust is also influenced by the dust removal method used. These problems are discussed on the basis of a wide range of numerical data.

APPENDIX C

REFERENCE 8 AND SUPPORTING DATA

ASPHALTIC CONCRETE PLANTS
ATMOSPHERIC EMISSIONS STUDY

EPA CONTRACT #68-02-0076

Prepared for

ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF AIR PROGRAMS
Research Triangle Park, North Carolina 27711

Prepared by

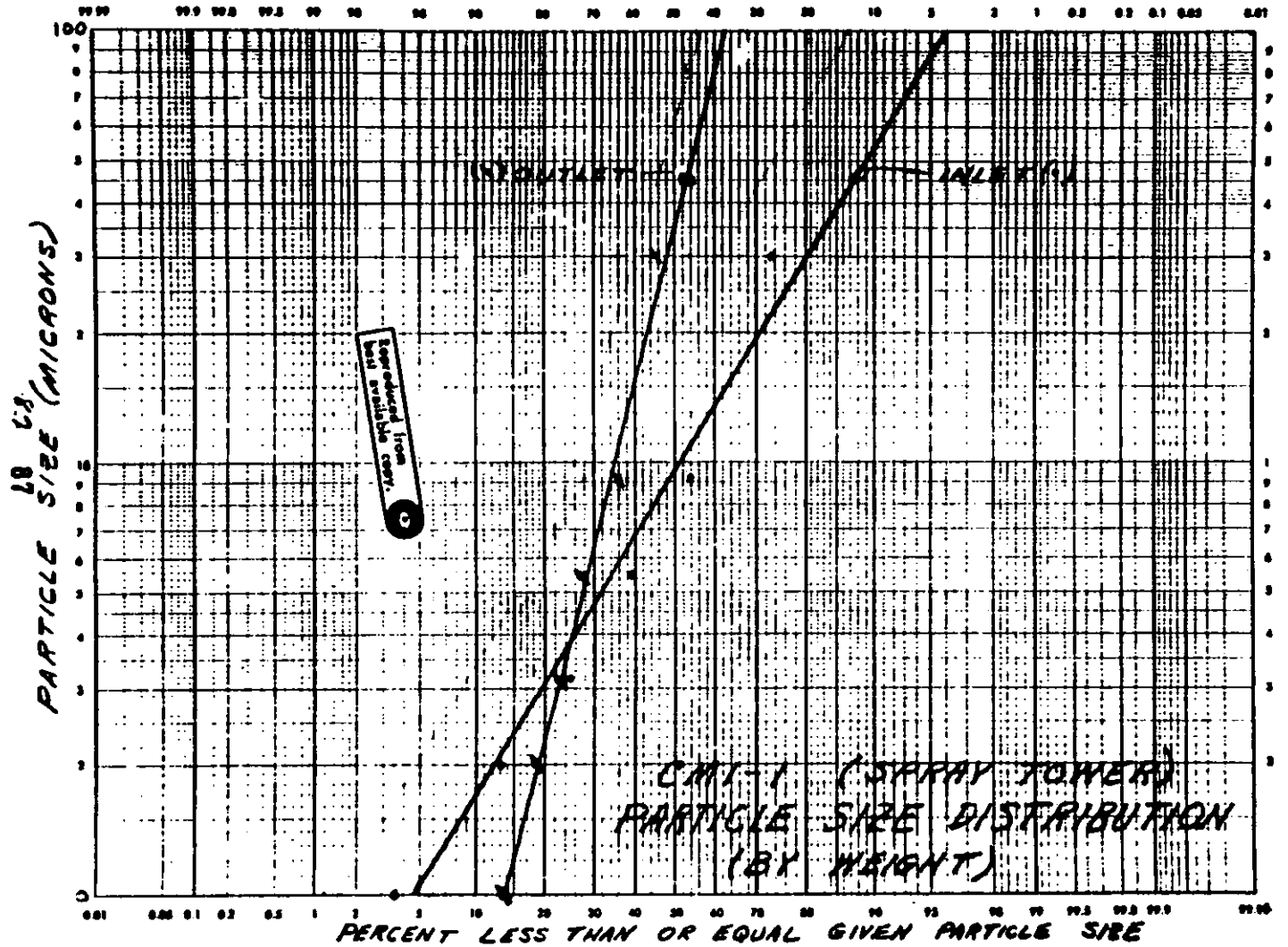
VALENTINE, FISHER & TOMLINSON
Consulting Engineers
520 Lloyd Building
Seattle, Washington 98101
(206) 623-0717

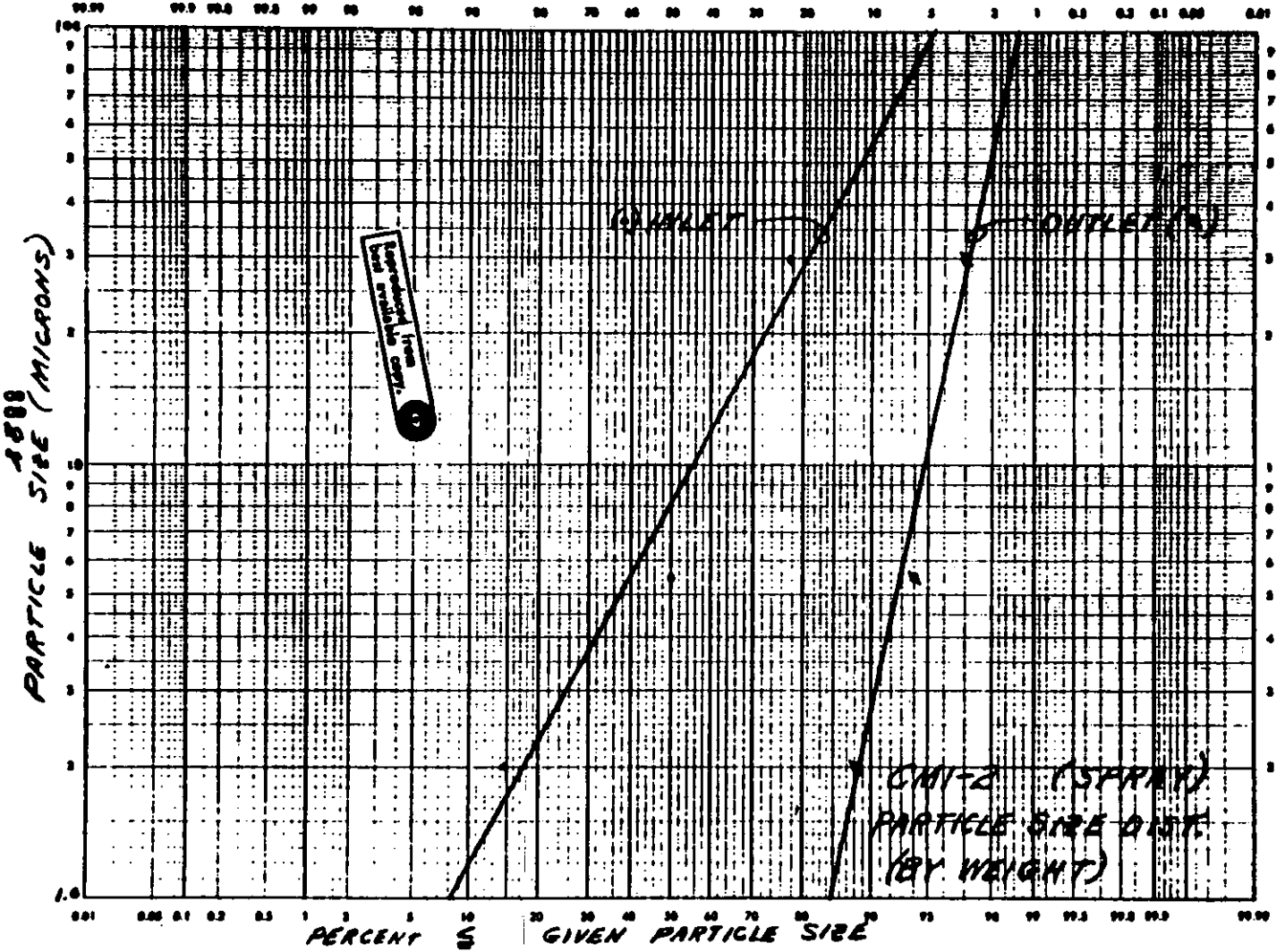
Authors

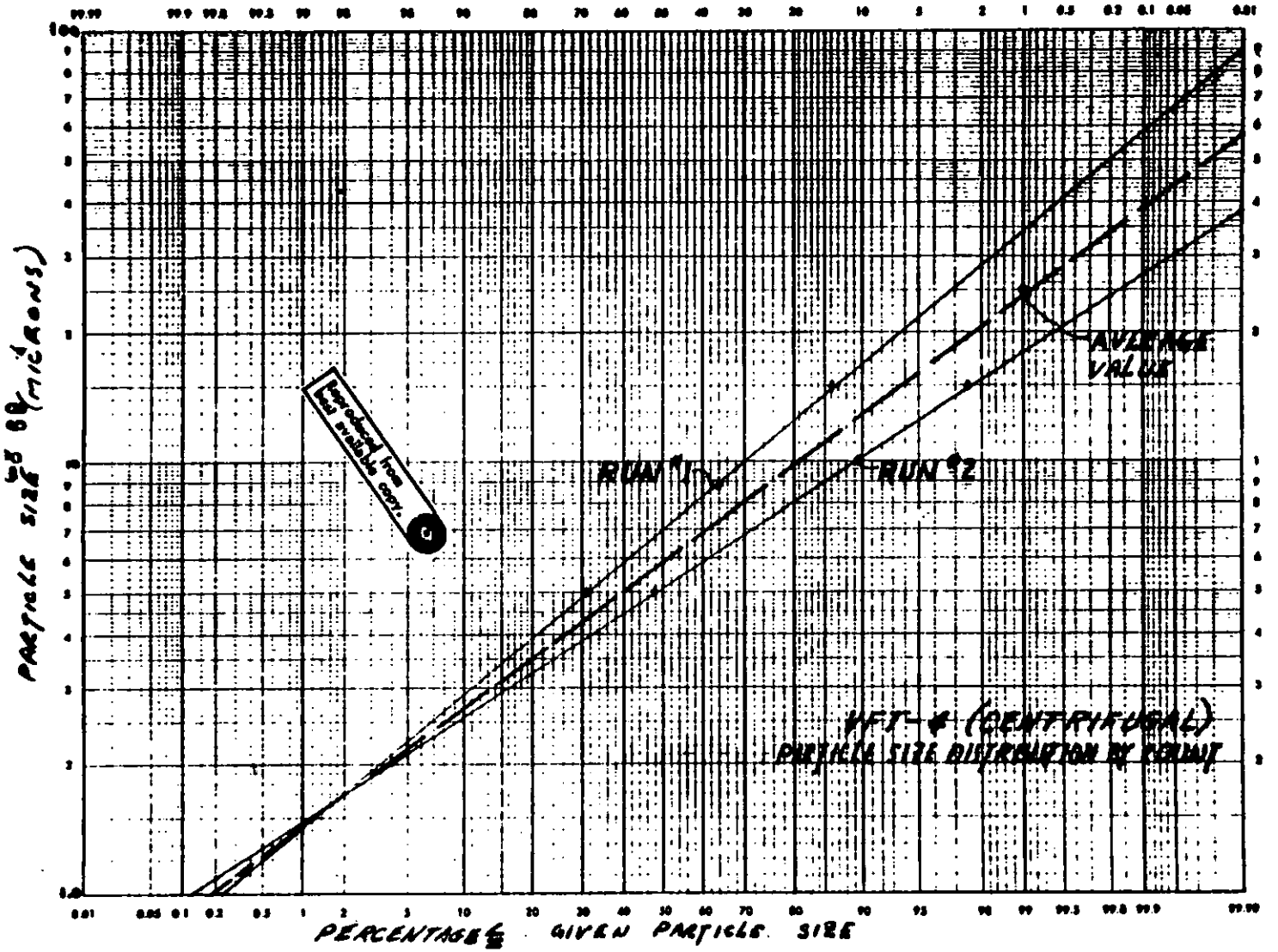
J.A. Crim
Crim Engineering
Seattle, Washington

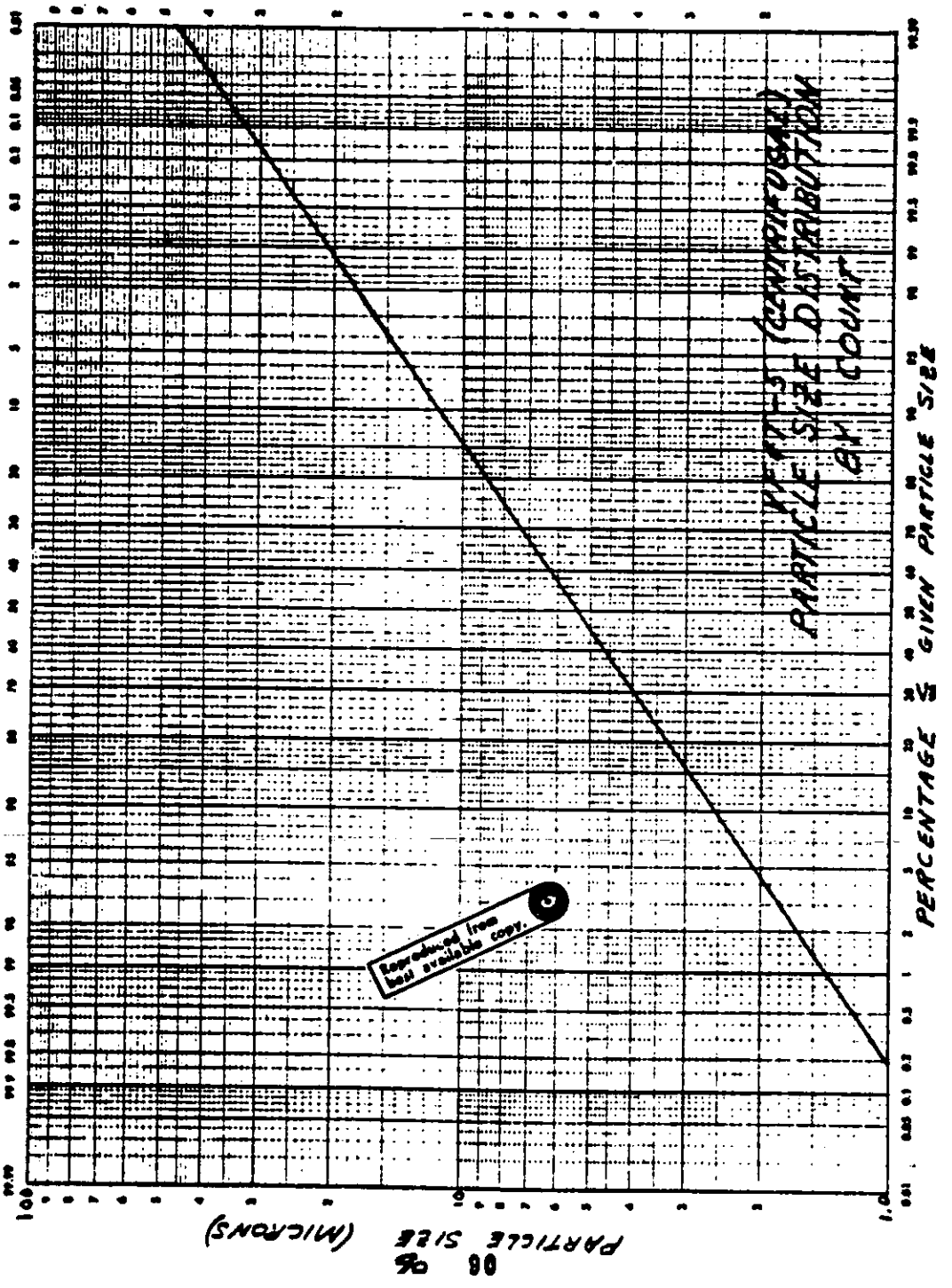
W.D. Snowden
Valentine, Fisher & Tomlinson

November 1, 1971


PARTICLE SIZE IN (MICRONS)
PERCENT LESS THAN OR EQUAL GIVEN PARTICLE SIZE
OUTLET (1)
INLET (1)
Reproduced from best available copy.
CMI-1 (SPRAY TOWER)
PARTICLE SIZE DISTRIBUTION
(BY WEIGHT)


PARTICLE SIZE (MICRONS)
PERCENT ≤ GIVEN PARTICLE SIZE
CWI-2 (SPRAY)
PARTICLE SIZE DIST.
(BY WEIGHT)


PARTICLE SIZE IN (MICRONS)
PERCENTAGE BY GIVEN PARTICLE SIZE
RUN #1
RUN #2
AVERAGE VALUE
WET - # (CENTRIFUGAL)
PARTICLE SIZE DISTRIBUTION BY PERMIT
Reproduced from best available copy.


PARTICLE SIZE DISTRIBUTION
BY COUNT
PERCENTAGE ≤ GIVEN PARTICLE SIZE
PARTICLE SIZE (MICRONS)
Reproduced from best available copy.

CONSULTANTS
AIR, WATER, ENERGY, HYGIENE & MANAGEMENT

May 14, 1982

Midwest Research Institute
425 Volker Blvd.
Kansas City, MO 64110

Attn: Mr. John Kinsey

Dear John,
Re: Original Particle Size Data from EPA Asphaltic Concrete Plants Emissions

The original field data to the subject report is enclosed. May I provide any clarification? Thank you for having us help you on your study.

Yours truly,
ASA CONSULTANTS

Wesley D. Snowden, P.E.

Enclosures

John –
Particle size data from UFAT not kept. Data was from observing & counting particles from (on) filter using a microscope. May I clarify?

1805 - 136th Place N.E., Suite 104, Bellevue, WA 98005, (206) 641-5130

ENVIRONMENTAL PROTECTION AGENCY
AIR POLLUTION CONTROL OFFICE (APCO)

ASPHALT BATCHING PLANT EMISSION DATA COMPILATION
PART I - PLANT INFORMATION

DATA IDENTIFICATION Sloan Construction Co.

PLANT GEOGRAPHICAL LOCATION Liberty, S.C.

TYPE OF RAW MATERIAL PROCESSED Crushed granite and sand aggregate

PLANT CAPACITY 10,000# Barber-Greene

PLANT PRODUCTION RATE (DURING EVALUATION) 225 tons/hr

TYPE OF CONTROL SYSTEM Cyclone and wet washer

AIR FLOW RATE (cfm) 37,900 @ 210 °F & 9 "H_2O Static across the fan

LOCATION OF SAMPLING PORT (NOTE OBSTRUCTIONS)
1. Washer inlet 2. Exhaust stack at washer outlet
34½"x39" sq. duct 6 foot diam - 2 ports at 15 foot downstream from stack inlet

CONTROL EQUIPMENT DESCRIPTION See attached sheet

PRESSURE DROP

BRAND AND SIZE OF CONTROL EQUIPMENT

WATER USAGE, ETC.

PARTICLE SIZE DISTRIBUTION (WEIGHT OR COUNT) See attached report

AVAILABLE COST INFORMATION Not available

PURCHASE COST

OPERATING COST

MAINTENANCE COST

EVAPORATION LOSSES

COMMENTS:

The system described was replaced in the early part of 1971 with a DP-710 Dynamic Precipitator System furnished by CMI Systems, Chattanooga, Tennessee.

ENVIRONMENTAL PROTECTION AGENCY
AIR POLLUTION CONTROL OFFICE (APCO)

ASPHALT BATCHING PLANT EMISSION DATA COMPILATION
PART II - SAMPLE INFORMATION

DATA Identification (Port, Etc.) _____

TYPE OF STACK GAS SAMPLING TRAIN Anderson - See attached sheet

DRY GAS VOLUME RECORDED ON GAS METER (FT^3) _____

PRESSURE OF METER (Inches Hg) _____

AVERAGE TEMPERATURE OF DRY GAS METER (°R) _____

VOLUME OF H_2O COLLECTED IN TRAIN (ml) _____

VOLUME OF WATER VAPOR PASSING THROUGH DRY GAS METER (FT^3 @ METER TEMPERATURE AND PRESSURE) _____

% MOISTURE IN STACK GAS (%) 115° F.D.B./115° F.W.B.

MOLECULAR WEIGHT OF DRY STACK GAS (LB/LB MOLE) _____

$\%CO_2$ _____
$\%O_2$ _____
%CO _____

STACK PRESSURE AT SAMPLING PORT (Inches Hg) _____

STACK GAS TEMPERATURE (°R) AND PITOT TUBE READING ("H_2O) @ EACH TRAVERSE POINT:

#1	&		#6	&		#11	&		#16	&	
#2	&		#7	&		#12	&		#17	&	
#3	&		#8	&		#13	&		#18	&	
#4	&		#9	&		#14	&		#19	&	
#5	&		#10	&		#15	&		#20	&	

TYPE PITOT TUBE USED W/ COEFFICIENT Stype WITH .82

AREA OF STACK @ PORT (FT^2) 28.3

SAMPLING TIME (MIN.) 5

TOTAL PARTICULATE (LESS BLANKS ON CLEAN-UP MATERIALS)

FILTER FINAL WT. (mg) _____ - TARE (mg) _____ = _____
TYPE OF FILTER _____
ACETONE RINSE OF PROBE & PREFILTER (mg) _____
ETHER AND CHLOROFORM EXTRACTION ON
BUBBLERS & IMPINGER WATER (mg) _____
H_2O EVAPORATION FROM IMPINGERS AND BUBBLERS _____
ACETONE RINSE OF GLASSWARE (mg) _____
TOTAL PARTICULATE (mg) 99.4 on all plates

COMMENTS:

Air Pollution Test
December 1, 1970
Sloan Construction Company
Liberty, South Carolina

Date Performed: December 1, 1970

Report by: W. Norman Smith, P. E.

Test Conducted By:

Norman Smith

Jim Campbell

A DIVISION OF CMI CORPORATION

cmi systems

P.O. Box 6249 • 1617 W.
Chattanooga, Tenness
(615)

No longer in business. 5/26/82

I. INTRODUCTION

The purpose of the air pollution tests was to determine the emission rates and particle size distribution at the hot mix asphalt plant owned by Sloan Construction Company, Liberty, South Carolina. A study of the present equipment and the equipment necessary to conform to the State of South Carolina Air Pollution codes were additional primary objectives.

By taking test samples at the air washer entrance and exit, the performance of the air washer could be evalutated.

The Anderson Stack Sampler was used as a fractionating device to determine the particulate distribution as well as emission rate.

III. TEST PROCEDURE

Each of the test locations were tested according to the following procedure:

1. The average velocity of the gas stream was determined using a special Pitot tube and an inclined manometer to traverse the duct. The flow rate of the gas stream was then calculated using the average velocity and the cross-section area of the duct. Test points were located as recommended by Bulletin WP-50, Joy Manufacturing Company. The correction factor of 0.82 as determined for previous calibration tests was used. The temperature of the gas stream was taken periodically to use in calculating density.

2. A reference station was selected to use as the point at which the sample was to be taken. The reference station velocity pressure was taken and the velocity calculated. In order to obtain an isokinetic sample the velocity into the sampling nozzle must be the same as the gas stream at the point of the sample. Using the known area of the sampler nozzle and the desired velocity, the required sampler flow rate was calculated.

3. The sampling apparatus consisted of a probe to insert into the gas stream with a nozzle on the probe of a known size, an Andersen stack sampler, a vaccum pump, and a flow meter to measure the total air flow through the sampler.

4. The samples were taken for periods that varied depending on the loading. Two samples were taken at each location. The sampler was heated while the sample was being taken to prevent condensation of water vapor on the sample plates. After allowing the plates to cool to room temperature the gross and the tare weight of each plate was recorded. The flow rate through the sampler which was determined from previous calculations and recorded.

5. Velocity traverse calculations were made as outlined by Bulletin WP-50, Joy Manufacturing Company.

IV. SUMMARY OF DATA

1. Location - Air Washer Exhaust Stack

Emission Rate	181 #/hr
Grains per cubic foot (Std. Cond.)	0.695
~~Micrograms per cubic meter (Std. Cond)~~	~~1.59 x 10^6~~
Dry Bulb Temp	115° F
Wet Bulb Temp	115° F
Air Flow at Duct Cond	32,600 ACFM
Air Flow at STD Cond	30,400 SCFM
No. of Samples	2

2. Location - Entrance to Air Washer

Emission Rate	2135 #/hr
Grains per cubic foot (Std. Cond)	8.2 Gr/c.f.
~~Micrograms per Cubic Meter (Std. Cond)~~	~~18.7 x 10^6~~
Dry Bulb Temperature	210° F
Wet Bulb Temperature	210° F
Air Flow At Duct Cond	37,900 ACFM
Air Flow At STD. Cond	30,400 SCFM
No. of Samples	2

3. Fan Data:

Clarage Size 141XL
Motor - 100 H.P.
Motor RPM - 1760
Motor Full Load AMPS - 116
Motor Operating Loan AMPS - 90
Fan RPM - 650
Operating Static Pressure Across Fan - 9.0 in. W. C.

MICRON SIZE	WASHER INLET %	WASHER INLET #/HR	WASHER EXHAUST %	WASHER EXHAUST #/HR	EFFN.
30 & larger	27.7	596	54.8	99.2	83.4
9.2 to 30	19.0	409	9.2	16.6	96.0
5.5 to 9.2	14.8	318	8.3	15.0	95.3
3.3 to 5.5	13.3	286	4.7	8.5	97.0
2.0 to 3.3	12.2	262	4.4	8.0	97.0
1.0 to 2.0	9.5	204	4.9	8.9	95.6
.3 to 1.0	2.3	50	8.0	14.5	71.0
.1 to .3	0.7	15	5.7	10.3	31.0
TOTAL		2135		181.0	91.7

CMI-1 ORIGINAL DATA
5/13/82

(THESE DATA REPRODUCED IN TABLE 3-8)

	1.	2.
Control Equip. Descrip.	Single cyclone	50 foot Horizontal Air Washer
Pressure Drop	3 – 4 in. W.C.	3 – 5 in. W.C.
Brand & Size of Equip.	Esstee – 9 foot Diameter	7 foot Diameter x 50 feet long
Water Usage	None	150 - 200 GPM

II. EQUIPMENT

1. Special Pitot Tube
2. Dryer Inclined Manometer
3. Andersen Stack Sampler
4. Dry and Wet Bulb Thermometer
5. Vacuum Pump and Sampling Train
6. Torbal Precision Balance (Accurate to 1/10,000 gram)

OWNER'S EQUIPMENT TESTED

1. Barber-Greene Batch Plant
2. Cyclone Dust Collector
3. Clarage 14LXL Exhaust Fan
4. Horizontal Air Washer

ENVIRONMENTAL PROTECTION AGENCY
AIR POLLUTION CONTROL OFFICE (APCO)

ASPHALT BATCHING PLANT EMISSION DATA COMPILATION
PART I - PLANT INFORMATION

DATA IDENTIFICATION Harrison, Inc.

PLANT GEOGRAPHICAL LOCATION Maryville, Tennessee

TYPE OF RAW MATERIAL PROCESSED Limestone and sand aggregate

PLANT CAPACITY 6,000 lb. batch

PLANT PRODUCTION RATE (DURING EVALUATION) 180 tons per hour

TYPE OF CONTROL SYSTEM Dry cyclone, pre-washer and cent. washer

AIR FLOW RATE (cfm) 31,500 @ 70 °F & _____ "H_2O

LOCATION OF SAMPLING PORT (NOTE OBSTRUCTIONS) Two ports at 90° in a six foot diameter exhaust stack approximately 20 feet downstream from the stack inlet.

I. CONTROL EQUIPMENT DESCRIPTION Centrifugal spray washer - vertical

PRESSURE DROP 3 in. W.C.
BRAND AND SIZE OF CONTROL EQUIPMENT Simplicity - 10 foot diameter
WATER USAGE, ETC. 150 - 200 GPM

See attached sheet for items 2 and 3.
PARTICLE SIZE DISTRIBUTION (WEIGHT OR COUNT) See attached chart

AVAILABLE COST INFORMATION

PURCHASE COST
OPERATING COST
MAINTENANCE COST

EVAPORATION LOSSES

COMMENTS:

This system when tested was emitting 63 lbs/hr which was over the Tennessee code. The contractor has now installed a CMI Systems DP-710 which is a Dynamic Precipitator System. I will be glad to furnish the test information to you as soon as it is complete.

ENVIRONMENTAL PROTECTION AGENCY
AIR POLLUTION CONTROL OFFICE (APCO)

ASPHALT BATCHING PLANT EMISSION DATA COMPILATION
PART II - SAMPLE INFORMATION

DATA Identification (Port, Etc.) _____

TYPE OF STACK GAS SAMPLING TRAIN Anderson

DRY GAS VOLUME RECORDED ON GAS METER (FT^3) 35.57

PRESSURE OF METER (Inches Hg) 29.92"

AVERAGE TEMPERATURE OF DRY GAS METER (°R) 80°F

VOLUME OF H_2O COLLECTED IN TRAIN (ml) _____

VOLUME OF WATER VAPOR PASSING THROUGH DRY GAS METER (FT^3 @ METER TEMPERATURE AND PRESSURE) 1.5 ft³ 20

% MOISTURE IN STACK GAS (%) _____

D.B. Temp = 112°F W.B. Temp = 112°F
MOLECULAR WEIGHT OF DRY STACK GAS (LB/LB MOLE) _____

%CO_2 _____
%O_2 _____
%CO _____

STACK PRESSURE AT SAMPLING PORT (Inches Hg) _____

STACK GAS TEMPERATURE (°R) AND PITOT TUBE READING ("H_2O) @ EACH TRAVERSE POINT:

#1	0.40	&		#6	0.375	&		#11	0.32	&	572	#16		&	
#2	0.40	&		#7	0.32	&		#12	0.30	&		#17		&	
#3	1.35	&		#8	0.375	&		#13		&		#18		&	
#4	0.30	&		#9	0.19	&		#14		&		#19		&	
#5	0.32	&		#10	0.32	&		#15		&		#20		&	

TYPE PITOT TUBE USED W/ COEFFICIENT S Type WITH .83

AREA OF STACK @ PORT (FT^2) 12.5 sq. ft.

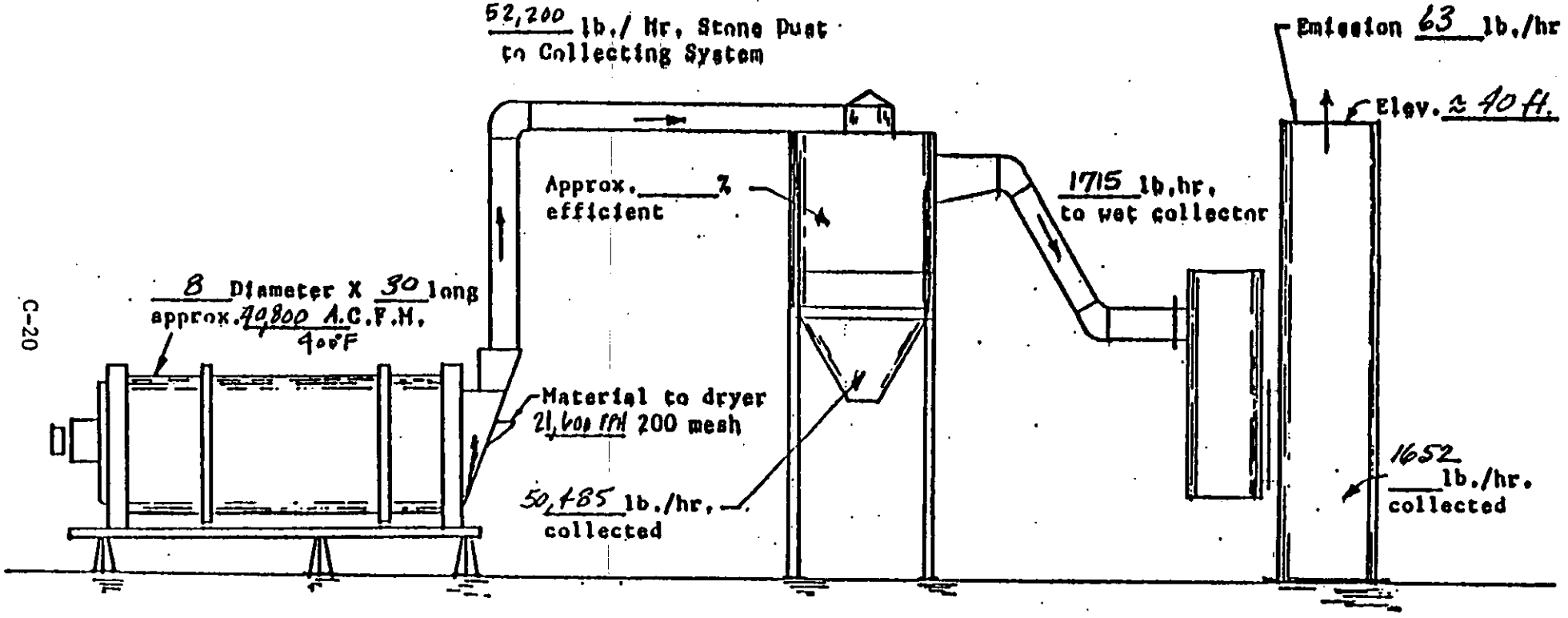
SAMPLING TIME (MIN.) 5 minutes

TOTAL PARTICULATE (LESS BLANKS ON CLEAN-UP MATERIALS)

FILTER FINAL WT. (mg) _____ - TARE (mg) _____ = _____
TYPE OF FILTER _____
ACETONE RINSE OF PROBE & PREFILTER (mg) _____
ETHER AND CHLOROFORM EXTRACTION ON
BUBBLERS & IMPINGER WATER (mg) _____
H_2O EVAPORATION FROM IMPINGERS AND BUBBLERS _____
ACETONE RINSE OF GLASSWARE (mg) _____
TOTAL PARTICULATE (mg) _____

ESTIMATED EMISSION RATES

Harrison, Inc.
Alcoa, Tenn.



C-20

Dryer Discharge
180 TPH to plant

Note:

1. Emission rates may vary from those shown. However these valves are an estimate based on actual results and with material which weights 100 lbs./cu. ft.

2. Exhaust fan for draft not shown

Dry Coll. Eff. = $\frac{50,485}{52,200}$ = 96.7%

Wet Sys. Eff. = $\frac{1652}{1715}$ = 96.3%

2. Control Equipment Description: Pre-washer

Pressure drop: 3 in. W.C.

Brand and size of equipment: Simplicity - 7 foot

Water usage: 30 - 50 GPM

3. Control Equipment Description: Cyclone

Pressure drop: 4 - 5 in. W.C.

Brand and size of equipment: Simplicity - 9 foot diam.

Water usage: None

HARRISON, INC. - HARYVILLE, TENN.

MICRON SIZE	PRE-WASH ENTRANCE %	PRE-WASH ENTRANCE #/HR	WASHER EXHAUST %	WASHER EXHAUST #/HR	EFF. %
30 & larger	23.1	396.2	3.0	1.9	98.9%
5.5 to 30	26.9	461.3	2.2	1.4	99.7%
2.0 to 5.5	35.1	602.0	6.8	4.3	99.3%
Smaller than 2.0	14.9	255.5	88.0	55.4	78.3%
		1715.0		63.0	

$$\text{OVERALL EFF.} = \frac{1715 - 63}{1715} = \frac{1652}{1715} = 96.3\%$$

(THESE DATA REPRODUCED IN TABLE 3-9)

APPENDIX D

REFERENCE 12

AIR POLLUTION ENGINEERING MANUAL

SECOND EDITION

Compiled and Edited
by
John A. Danielson

AIR POLLUTION CONTROL DISTRICT
COUNTY OF LOS ANGELES

ENVIRONMENTAL PROTECTION AGENCY
Office of Air and Water Programs
Office of Air Quality Planning and Standards
Research Triangle Park, N.C. 27711

May 1973

D-2

CHAPTER 7

MECHANICAL EQUIPMENT

HOT-MIX ASPHALT PAVING BATCH PLANTS

INTRODUCTION

Hot-mix asphalt paving consists of a combination of aggregates* uniformly mixed and coated with asphalt cement. An asphalt batch plant is used to heat, mix, and combine the aggregate and asphalt in the proper proportions to give the desired paving mix. After the material is mixed, it is transported to the paving site and spread as a loosely compacted layer with a uniformly smooth surface. While still hot, the material is compacted and densified by heavy motor-driven rollers to produce a smooth, well-compacted course.

Asphalt paving mixes may be produced from a wide range of aggregate combinations, each having particular characteristics and suited to specific design and construction uses. Aside from the amount and grade of asphalt cement used, the principal characteristics of the mix are determined by the relative amounts of:

Coarse aggregate (retained on No. 8-mesh sieve), fine aggregate (passing No. 8-mesh sieve), and mineral dust (passing No. 200-mesh sieve).

The aggregate composition may vary from a coarse-textured mix having a predominance of coarse aggregate to a fine-textured mix having a predominance of fine aggregate. The Asphalt Institute (1957) classifies hot-mix asphalt paving according to the relative amounts of coarse aggregate, fine aggregate, and mineral dust. The general limits for each mix type are shown in Table 91. The compositions used within each mix type are shown in Tables 92 and 93.

Raw Materials Used

Aggregates of all sizes up to 2-1/2 inches are used in hot-mix asphalt paving. The coarse aggregates usually consist of crushed stone, crushed slag, crushed gravel, or combinations thereof, or of material such as decomposed granite naturally occurring in a fractured condition, or of a highly angular natural aggregate with a pitted or rough surface texture. The fine aggregates usually consist of natural sand and may contain added materials such as crushed stone, slag, or gravel. All aggregates must be free from coatings of clay, silt, or other objectionable matter and should not contain clay particles or other fine materials. The aggregate must also meet tests for soundness (ASTM designation C88) and wearability (ASTM designation C131).

Mineral filler is used in some types of paving. It usually consists of finely ground particles of crushed rock, limestone, hydrated lime, Portland cement, or other nonplastic mineral matter. A minimum of 65 percent of this material must pass a 200-mesh sieve. Another name for mineral filler is mineral dust.

Asphalt cement is used in amounts of 3 to 12 percent by weight and is made from refined petroleum. It is a solid at ambient temperature but is usually used as a liquid at 275° to 325°F. One property measurement used in selecting an asphalt cement is the "penetration" as determined by ASTM Method D5. The most common penetration grades used in asphalt paving are 60 to 70, 85 to 100, and 120 to 150. The grade used depends upon the type of aggregate, the paving use, and the climatic conditions.

Basic Equipment

A typical hot-mix asphalt paving batch plant usually consists of an oil- or gas-fired rotary drier, a screening and classifying system, weigh boxes for asphalt cement and aggregate, a mixer, and the necessary conveying equipment consisting of bucket elevators and belt conveyors. Equipment for the storage of sand, gravel, asphalt cement, and fuel oil is provided in most plants. Heaters for the asphalt cement and fuel oil tanks are also used.

Plant Operation

Plants vary in size. The majority in Los Angeles County produce 4,000-pound batches and have production rates of 100 to 150 tons of asphalt paving mix per hour. Some of the newer plants are 6,000-pound batch size and are capable of producing 150 to 250 tons per hour.

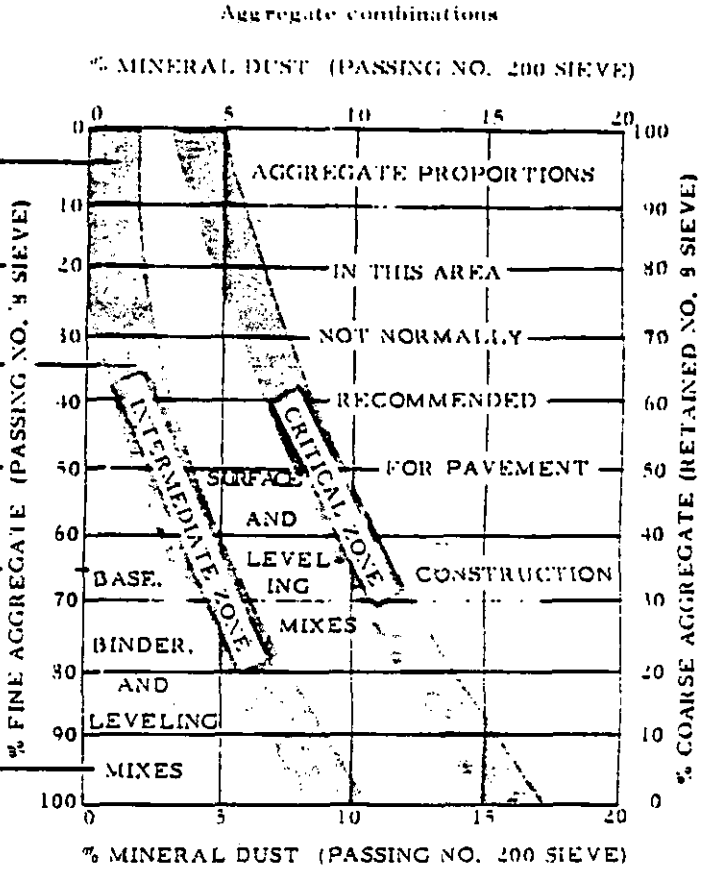
*Aggregate is a term used to describe the solid mineral load-bearing constituents of asphalt paving such as sand particles and fragments of stone, gravel, and so forth.

Table 91. CLASSIFICATION OF HOT-MIX ASPHALT PAVING
(The Asphalt Institute, 1957)

Paving mix designation		Maximum size aggregate normally used	
Type	Description	Surface and leveling mixes	Base, binder, and leveling mixes
I	Macadam		2-1/2 in.
II	Open graded	3/8 to 3/4 in.	3/4 to 1-1/2 in.
III	Coarse graded	1/2 to 3/4 in.	3/4 to 1-1/2 in.
IV	Dense graded	1/2 to 1 in.	1 to 1-1/2 in.
V	Fine graded	1/2 to 3/4 in.	3/4 in.
VI	Stone sheet	1/2 to 3/4 in.	3/4 in.
VII	Sand sheet	3/8 in.	3/8 in.
VIII	Fine sheet	No. 4	No. 4

[a]Critical zone - Dust contents in this region should not be used without a substantial background of experience with such mixes and/or suitable justification by laboratory design tests.

[b]Intermediate zone - Dust contents in this region sometimes used in surface and leveling mixes as well as in base and binder mixes.



{115-120 lb/ft³ loose storage
{146 lb/ft³ rolled & cold

Standard asphalt paving densities

Figure 221 is a flow diagram of a typical plant. Aggregate is usually conveyed from the storage bins to the rotary drier by means of a belt conveyor and bucket elevator. The drier is usually either oil- or gas-fired and heats the aggregate to temperatures ranging from 250° to 350°F. The dried aggregate is conveyed by a bucket elevator to the screening equipment where it is classified and dumped into elevated storage bins. Selected amounts of the proper size aggregate are dropped from the storage bins to the weigh hopper. The weighed aggregate is then dropped into the mixer along with hot asphalt cement. The batch is mixed and then dumped into waiting trucks for transportation to the paving site. Mineral filler can be added directly to the weigh hopper by means of an auxiliary bucket elevator and screw conveyor.

Fine dust in the combustion gases from the rotary drier is partially recovered in a precleaner and discharged continuously into the hot dried aggregate leaving the drier.

THE AIR POLLUTION PROBLEM

The largest source of dust emissions is the rotary drier. Other sources are the hot aggregate bucket elevator, the vibrating screens, the hot aggregate bins, the aggregate weigh hopper, and the mixer. Rotary drier emissions up to 6,700 pounds per hour have been measured, as shown in Table 94. In one plant, 2,000 pounds of dust per hour was collected from the discharge of the secondary dust sources, that is, the vibrating screens, hot aggregate bins, the aggregate weigh hopper, and the mixer.

Table 92. COMPILATION OF SUGGESTED MIX COMPOSITIONS (The Asphalt Institute, 1957)

Mix type		Aggregate by size in mix, %												Asphalt, %
		1-1/2 in.	1 in.	3/4 in.	1/2 in.	3/8 in.	No. 4	No. 8	No. 16	No. 30	No. 50	No. 100	No. 200	
Mix aval	II a					100	40 to 85	5 to 20					0 to 4	4.0 to 5.0
	II b					70 to 100	20 to 40	5 to 20					0 to 4	4.0 to 5.0
	II b				100	70 to 100	20 to 40	5 to 20					0 to 4	4.0 to 5.0
	II c			100	70 to 100	45 to 75	20 to 40	5 to 20					0 to 4	3.0 to 6.0
S	III a				100	75 to 100	35 to 55	20 to 35		10 to 22	6 to 16	4 to 12	2 to 4	3.0 to 6.0
u	III b			100	75 to 100	60 to 80	35 to 55	20 to 35		10 to 22	6 to 16	4 to 12	2 to 4	3.0 to 6.0
r	IV a				100	80 to 100	55 to 75	35 to 50		19 to 30	13 to 23	7 to 16	4 to 10	3.5 to 7.0
f	IV b			100	90 to 100	70 to 90	40 to 70	25 to 50		19 to 30	13 to 23	7 to 16	4 to 10	3.5 to 7.0
a	IV c		100	90 to 100		60 to 80	48 to 65	35 to 50		19 to 30	13 to 23	7 to 16	4 to 10	3.5 to 7.0
c	V a				100	85 to 100	65 to 80	50 to 65	37 to 52	25 to 40	18 to 30	10 to 20	5 to 10	4.0 to 7.5
e	V b[a]			100	95 to 100		65 to 90	50 to 65	37 to 52	25 to 40	18 to 30	10 to 20	5 to 10	4.0 to 7.5
	VI a				100	95 to 100		65 to 90	50 to 70	35 to 60	25 to 48	15 to 30	6 to 12	4.5 to 9.5
	VI b[a]			100		95 to 100		65 to 90	47 to 68	30 to 55	20 to 40	10 to 25	3 to 8	4.5 to 9.5
	VII a[a]					100	95 to 100	90 to 95	70 to 89	45 to 80	30 to 60	10 to 35	4 to 14	6.0 to 11.0
	VIII a						100	95 to 100	85 to 95	70 to 95	40 to 75	20 to 40	4 to 16	6.5 to 12.0

[a]May be used for base where coarse aggregate is not economically available.

Table 93. COMPILATION OF SUGGESTED MIX COMPOSITIONS (The Asphalt Institute, 1957)

Mix type	2-1/2 in.	1-1/2 in.	1 in.	3/4 in.	1/2 in.	3/8 in.	No. 4	No. 8	No. 16	No. 30	No. 50	No. 100	No. 200	Asphalt, %
Binder														
IIc				100	70 to 100	45 to 75	20 to 40	5 to 20					0 to 4	3.0 to 6.0
II d			100	70 to 100		35 to 60	15 to 35	5 to 20					0 to 4	3.0 to 6.0
III b				100	75 to 100	60 to 85	35 to 55	20 to 35		10 to 22	6 to 16	4 to 12	2 to 4	3.0 to 6.0
III c				100	75 to 100	60 to 85	30 to 50	20 to 35		5 to 20	3 to 12	2 to 4	0 to 4	3.0 to 6.0
III d			100	75 to 100		45 to 70	30 to 50	20 to 35		5 to 20	3 to 12	2 to 4	0 to 4	3.0 to 6.0
IV c			100	90 to 100		60 to 80	48 to 65	35 to 50		19 to 30	13 to 23	7 to 16	0 to 4	3.5 to 7.0
Leveling														
III b				100	75 to 100	60 to 85	35 to 55	20 to 35		10 to 22	6 to 16	4 to 12	2 to 4	3.0 to 6.0
V b[a]				100	95 to 100		65 to 90	50 to 65	37 to 52	25 to 40	18 to 30	10 to 20	5 to 10	4.0 to 7.5
VI b[a]				100		95 to 100		65 to 90	47 to 68	30 to 55	20 to 40	10 to 25	3 to 8	4.5 to 9.5
Base														
I a	100	35 to 70		0 to 15				0 to 5					0 to 5	3.0 to 4.5
II d			100	70 to 100		35 to 60	15 to 35	5 to 20					0 to 4	3.0 to 6.0
II e		100	70 to 100	50 to 80		25 to 50	10 to 30	5 to 20					0 to 5	3.0 to 6.0
III d			100	75 to 100		45 to 70	30 to 50	20 to 35		5 to 20	3 to 12	2 to 4	0 to 4	3.0 to 6.0
III e		100	75 to 100	60 to 85		40 to 65	30 to 50	20 to 35		5 to 20	3 to 12	2 to 4	0 to 4	3.0 to 6.0
IV d		100	90 to 100	70 to 90		55 to 75	45 to 62	35 to 50		19 to 30	13 to 23	7 to 16	0 to 4	3.5 to 7.0

[a]May be used for base where coarse aggregate is not economically available.

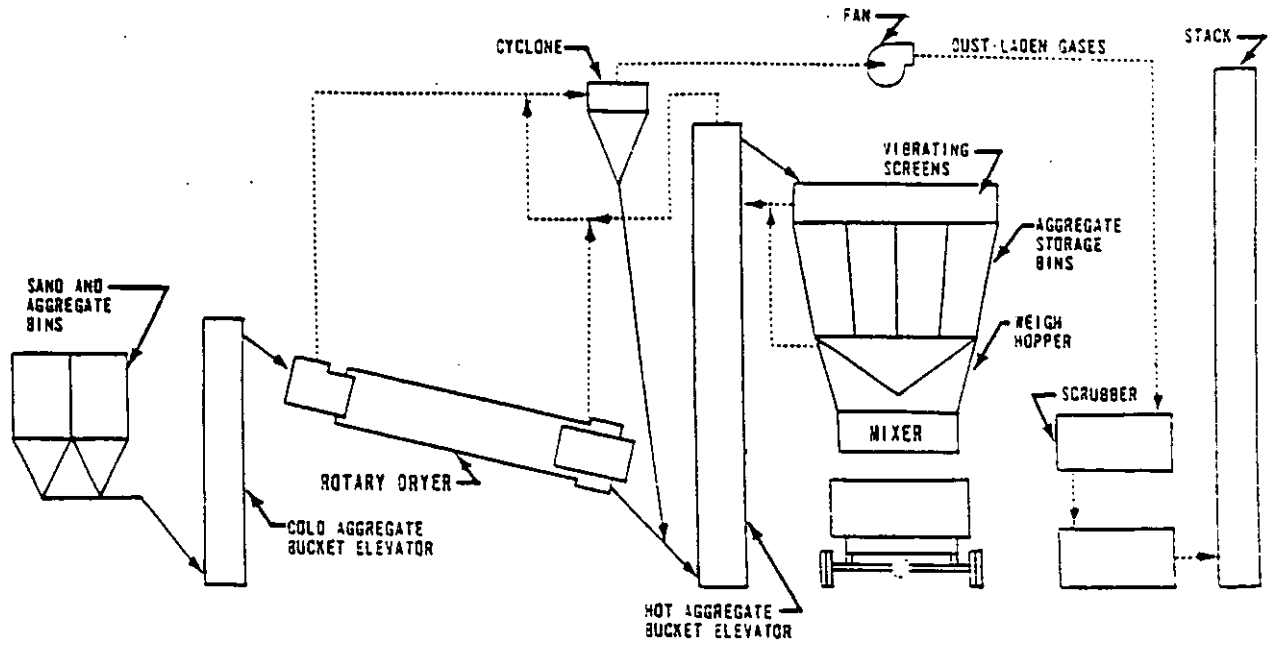


Figure 221. Flow diagram of a typical hot-mix asphalt paving batch plant.

Table 94. DUST AND FUME DISCHARGE FROM ASPHALT BATCH PLANTS

Test No.	C-426		C-537	
Batch plant data				
Mixer capacity, lb	6,000		6,000	
Process weight, lb/hr	364,000		346,000	
Drier fuel	Oil, PS300		Oil, PS300	
Type of mix	City street, surface		Highway, surface	
Aggregate feed to drier, wt %				
+10 mesh	70.8		68.1	
-10 to +100 mesh	24.7		28.9	
-100 to +200 mesh	1.7		1.4	
-200 mesh	2.8		1.6	
Dust and fume data	Vent line[a]	Drier	Vent line[a]	Drier
Gas volume, scfm	2,800	21,000	3,715	22,050
Gas temperature, °F	215	180	200	430
Dust loading, lb/hr	2,000	6,700	740	4,720
Dust loading, grains/scf	81.3	37.2	23.29	24.98
Sieve analysis of dust, wt %				
+100 mesh	4.3	17.0	0.5	18.9
-100 to +200 mesh	6.5	25.2	4.6	32.2
-200 mesh	89.2	57.8	94.9	48.9
Particle size of -200 mesh				
0 to 5 μ, wt %	19.3	10.1	18.8	9.2
5 to 10 μ, wt %	20.4	11.0	27.6	12.3
10 to 20 μ, wt %	21.0	11.0	40.4	22.7
20 to 50 μ, wt %	25.1	21.4	12.1	49.3
> 50 μ, wt %	14.2	46.5	1.1	6.5

[a] Vent line serves hot elevator, screens, bin, weigh hopper, and mixer.

(THESE DATA USED IN TABLE 3-10)

Drier dust emissions increase with air mass velocity, increasing rate of rotation, and feed rate, but are independent of drier slope (Friedman and Marshall, 1949). Particle size distribution of the drier feed has an appreciable effect on the discharge of dust. Tests show that about 55 percent of the minus 200-mesh fraction in the drier feed can be lost in processing. The dust emissions from the secondary sources vary with the amount of fine material in the feed and the mechanical condition of the equipment. Table 94 and Figure 222 give results of source tests of two typical plants. Particle size of the dust emissions and of the aggregate feed to the drier are also shown.

HOODING AND VENTILATION REQUIREMENTS

Dust pickup must be provided at all the sources of dust discharge. Total ventilation requirements vary according to the size of the plant. For a 6,000-pound-per-batch plant, 22,000 scfm is typical, of which 18,000 to 19,000 scfm is allotted for use in controlling the drier emissions. The top end of the drier must be closely hooded to provide for exhaust of the products of combustion and entrained dust. A ring-type hood located between the stationary portion of the burner housing and the drier provides satisfactory pickup at the lower end of the drier. An indraft velocity of 200 fpm should be provided at the annular opening between the circumference of the drier and the ring-type hood.

The secondary dust sources, that is, the elevator, vibrating screens, hot aggregate bins, weigh hopper, and mixer, are all totally enclosed, and hence, no separate hooding is required. Dust collection is provided by connecting this equipment through branch ducting to the main exhaust system. Approximately 3,000 to 3,500 scfm will adequately ventilate these secondary sources.

AIR POLLUTION CONTROL EQUIPMENT

Primary dust collection equipment usually consists of a cyclone. Twin or multiple cyclones are also used. The catch of the primary dust collector is returned to the hot bucket elevator where it continues on with the main bulk of the drier aggregate. The air discharge from the primary dust collector is ducted to the final dust collection system.

Two principal types of final control equipment have evolved from the many types employed over the years: The multiple centrifugal-type spray chamber (Figure 223) and the baffled-type spray tower

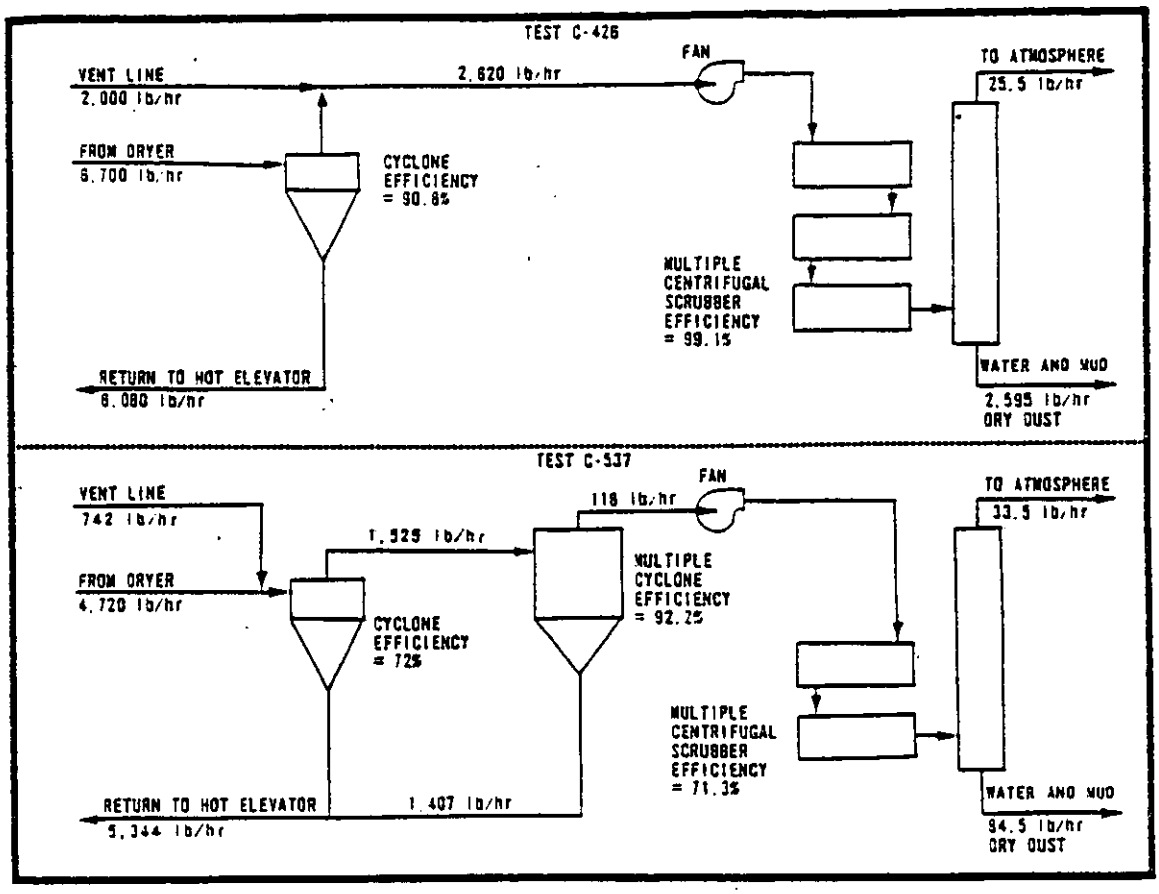


Figure 222. Test data on air pollution control equipment serving two hot-mix asphalt paving plants (vent line serves screens, hot bins, weigh hopper, and mixer).

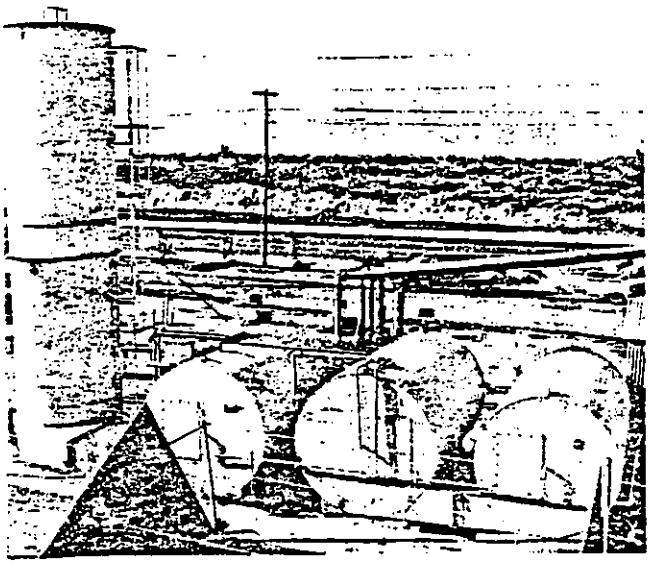


Figure 223. Typical multiple centrifugal-type scrubber serving a 4,000-pound-batch-capacity hot-mix asphalt paving plant.

(Figure 224). The multiple centrifugal-type spray chamber has proved the more efficient. It consists of two or more internally fluted, cylindrical spray chambers in which the dust-laden gases are admitted tangentially at high velocities. These chambers are each about the same size, that is, 6 feet in diameter by 15 feet in length, if two chambers are used, and 6 feet in diameter by 9 or 12 feet in length if three chambers are used. Usually 7 to 12 spray nozzles are evenly spaced within each chamber. The total water rate to the nozzles is usually about 70 to 250 gpm at 50 to 100 psi. In the baffled-type spray tower, there have been many variations and designs, but fundamentally, each consists of a chamber that is baffled to force the gases to travel in a sinuous path, which encourages impingement of the dust particles against the sides of the chamber and the baffles. Water spray nozzles are located among the baffles, and the water rate through the spray nozzles is usually between 100 to 300 gpm at 50 to 100 psi.

In both types of scrubber the water may be either fresh or recirculated. Settling pits or concrete tanks of sufficient capacity to allow most of the collected dust to settle out of the water are re-

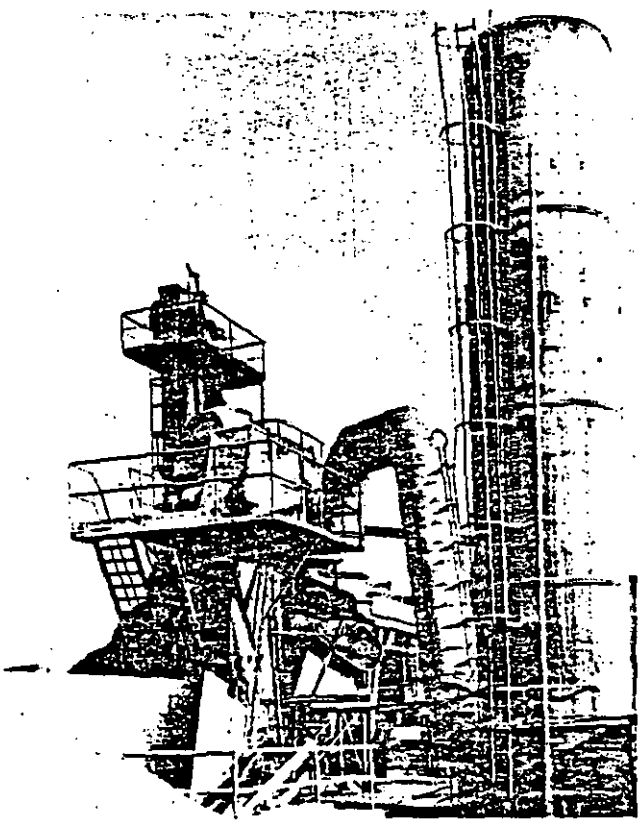


Figure 224. Typical baffled-type spray tower serving a 4,000-pound-batch-capacity hot-mix asphalt paving plant (Griffith Company, Wilmington, Calif.).

quired with a system using recirculated water. The scrubber catch is usually hauled away and discarded. It is usually unsuitable for use as mineral filler in the paving mix because it contains organic matter and clay particles. The recirculated water may become acidic and corrosive, depending upon the amount of sulfur in the drier fuel, and must then be treated with chemicals to protect the scrubber and stack from corrosion. Caustic soda and lime have been used successfully for this purpose.

Variables Affecting Scrubber Emissions

In a recent study (Ingels et al., 1960), many source tests (see Table 95) on asphalt paving plants in Los Angeles County were used to correlate the major variables affecting stack losses. Significant variables include the aggregate fines feed rate (the minus 200-mesh fraction), the type of fuel fired in the drier, the scrubber's water-gas ratio,* and the type of scrubber used. Other, less important variables were also revealed in the study.

*The water-gas ratio is defined as the total quantity of water sprayed in gallons per 1,000 scf of effluent gas.

The effect of aggregate fines feed rate on stack emissions at constant water-gas ratio (an average value for test considered) is shown in Figure 225 for multiple centrifugal-type scrubbers and baffled tower scrubbers. Stack emissions increase linearly with an increase in the amount of minus 200-mesh material processed. These losses can be greatly reduced by using a clean or washed sand. The required fines content of the hot-mix asphalt paving is then obtained by adding mineral filler directly to the plant weigh hopper by means of an auxiliary bucket elevator and screw conveyor.

Most asphalt paving batch plants burn natural gas. When gas is not available, and if permitted by law, a heavy fuel oil (U.S. Grade No. 6 or heavier) is usually substituted. Dust emissions to the atmosphere from plants with air pollution control devices were found to be about 5.1 pounds per hour greater when the drier was fired with oil than they were when the drier was fired with natural gas. The difference is believed to represent particulate matter residing in, or formed by, the fuel oil, rather than additional dust from the drier. Similarly, the burning of heavy fuel oils in other kinds of combustion equipment results in greater emissions of particulate matter.

The amount of water fed to the scrubber is a very important consideration. The spray nozzles should

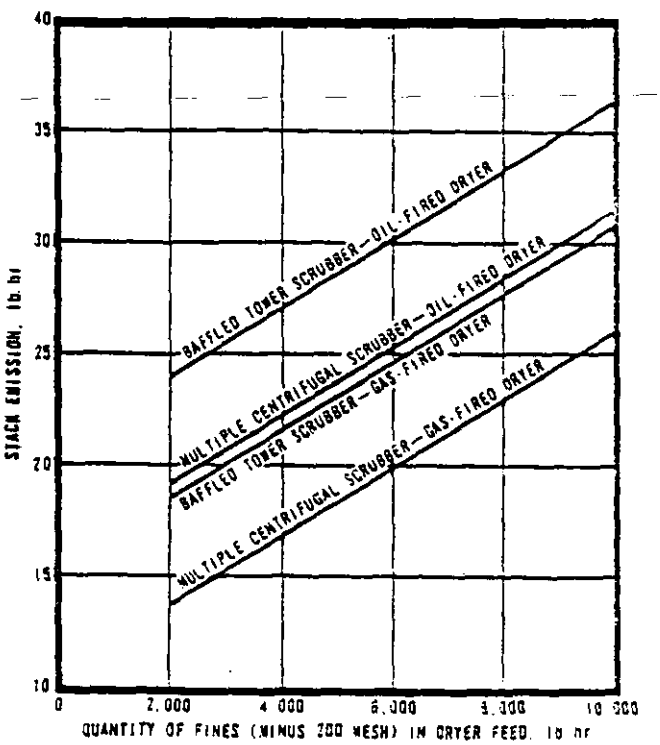


Figure 225. Effect of aggregate fines feed rate on stack emissions at average water-gas ratio (Ingels et al., 1960).

Table 95. TEST DATA FROM HOT-MIX ASPHALT PAVING PLANTS CONTROLLED BY SCRUBBERS

Test No.	Scrubber inlet dust loading, lb/hr	Stack emission, lb/hr	Aggregate fines rate,[a] lb/hr	Water-gas ratio, gal/1,000 scf	Overall scrubber efficiency, wt %	Type of scrubber[b]	Type of drier fuel	Production rate, tons/hr	Gas effluent volume, scfm
C-357	940	20.7	9,550	6.62	97.8	C	Oil	183.9	23,100
C-82	427	35.6	4,460	3.94	91.6	C	Oil	96.9	19,500
C-379	4,110	37.1	8,350	6.38	99.1	C	Oil	174.0	26,200
C-355	2,170	47.0	14,000	6.81	97.8	C	Oil	209.1	25,700
C-372B	121	19.2	2,290	10.99	84.2	C	Oil	142.9	18,200
C-372A	76	10.0	2,840	11.11	86.8	C	Gas	158.0	18,000
C-369	352	24.4	4,750	5.41	93.0	C	Oil	113.0	16,100
C-393	4,260	26.9	4,050	12.01	99.3	T	Oil	92.3	19,500
C-354	--	27.8	6,370	6.10	--	T	Oil	118.4	7,720
C-185	1,640	21.3	5,220	19.40	98.7	T	Oil	137.8	18,700
C-173	--	31.0	8,850	20.40	--	T	Oil	184.2	17,000
1	--	33.5	7,520	11.01	--	T	Oil	144.6	23,700
C-379	3,850	30.3	6,500	5.92	99.2	C	Gas	191.3	28,300
C-337	305	13.6	2,510	11.11	95.5	C	Oil	114.6	24,300
2	--	21.1	3,730	7.28	--	T	Gas	124.4	15,900
C-234	372	21.2	2,530	5.70	94.3	T	Gas	42.0	17,200
C-426	2,620	25.5	10,200	7.75	99.0	C	Oil	182.0	22,000
C-417	560	39.9	3,050	2.94	92.8	C	Oil	138.9	24,600
C-425	485	32.9	2,890	4.26	93.2	C	Oil	131.4	18,000
3	--	25.5	6,590	6.60	--	C	Gas	131.7	18,200
C-385	212	17.5	4,890	4.56	91.7	C	Oil	174.3	20,000
C-433	266	11.0	5,960	8.12	95.8	C	Gas	114.5	19,600
C-422(1)	--	26.6	7,140	4.90	--	C	Oil	198.0	21,000
C-422(2)	--	37.0	3,340	3.02	--	C	Oil	152.0	22,200
C-418	3,400	30.8	9,350	8.90	99.1	T	Oil	116.5	17,100
Averages		26.7	5,900		94.9				

[a]Quantity of fines (minus 200 mesh) in dryer feed.
[b]C = Multiple centrifugal-type spray chamber.
T = Baffled tower scrubber.

be located so as to cover the moving gas stream adequately with fine spray. Sufficient water should be used to cool the gases below the dew point. One typical scrubber tested had an inlet gas at 200°F with 16.8 percent water vapor content by volume, and an outlet gas at 131°F with 16.3 percent water vapor and saturated. The temperature at the gas outlet of efficient scrubbers rarely exceeds 140°F, and the gas is usually saturated with water vapor.

Figure 226 shows the effect of the scrubber's water-gas ratio on dust emissions with the aggregate fines feed rate held constant (an average value for the test considered). Efficient scrubbers use water at rates of 6 to 10 gallons per 1,000 standard cubic feet of gas. The efficiency falls off rapidly at water rates less than 6 gallons per 1,000 scf of gas. At rates of more than 10 gallons per 1,000 scf of gas, the efficiency still increases, but at a lesser rate.

Curves are presented in Figures 227 and 228 from which probable stack emissions can be predicted for oil- and gas-fired plants with either multiple centrifugal or baffled tower scrubbers. These curves present emissions for various scrubbers' water-gas ratios and aggregate fines rates. Emission predictions from these curves are accurate only for plants of the type and design already discussed.

The operation of the rotary drier is also an important variable. Dust emissions increase with an increase of air mass velocity through the drier. Obviously then, care should be taken to operate the drier without a great amount of excess air. This care effects fuel economy and reduces dust emissions from the drier.

The firing rate of the drier is determined by the amount of moisture in the aggregate and by the required hot aggregate temperature. The greater the aggregate moisture content, the greater the firing rate and the resulting dust emissions to the atmosphere. In some plants, the increase in moisture content of the flue gases may increase the efficiency of the scrubber sufficiently to offset the increase in dust emissions from the drier.

Scrubber efficiencies also vary according to the degree of precleaning done by the primary dust collector. Tests (such as those presented in Table 95) have shown that overall efficiency of the pre-

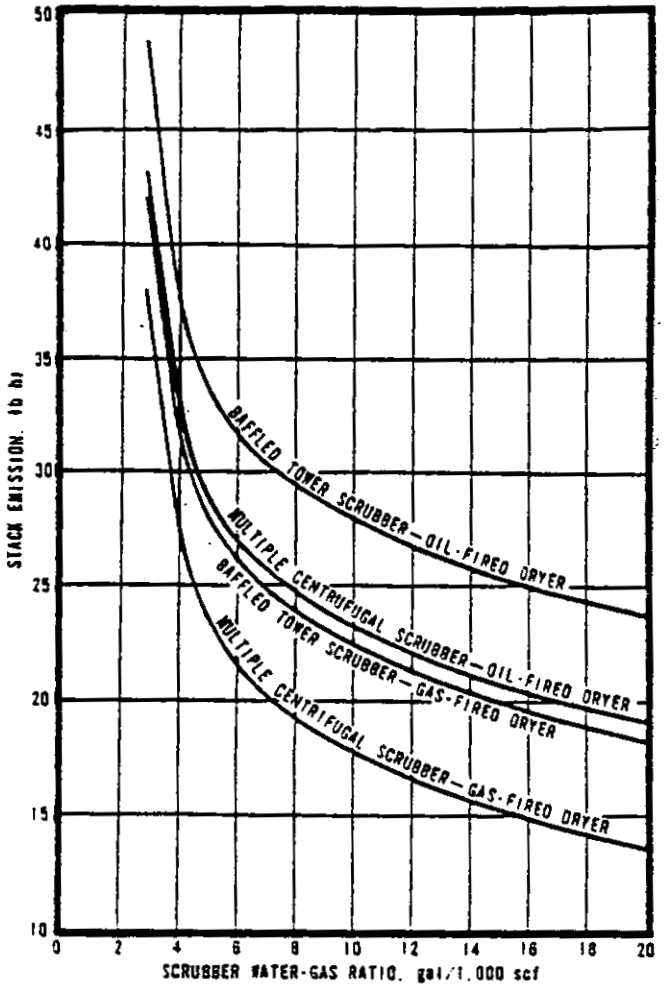


Figure 226. Effect of scrubber's water-gas ratio on stack emissions at average aggregate fines feed rate in the drier feed (Ingels et al., 1960).

cleaner and final collector varies only slightly with large variations in precleaner efficiency. Plants with less effective cyclone precleaning had, on the average, larger particles entering the scrubber, and consequently, show greater scrubber collection efficiencies. The principal advantage of an efficient precleaner is that the valuable fines collected can be discharged directly to the hot elevator for use in the paving mix. Furthermore, less dust is discharged to the scrubber, where more troublesome dust disposal problems are encountered.

Collection Efficiencies Attained

Collection efficiencies of cyclonic-type precleaners vary from approximately 70 to 90 percent on an overall weight basis. Scrubber efficiencies varying from 35 to nearly 100 percent have been found. Overall collection efficiencies usually vary between 95 and 100 percent.

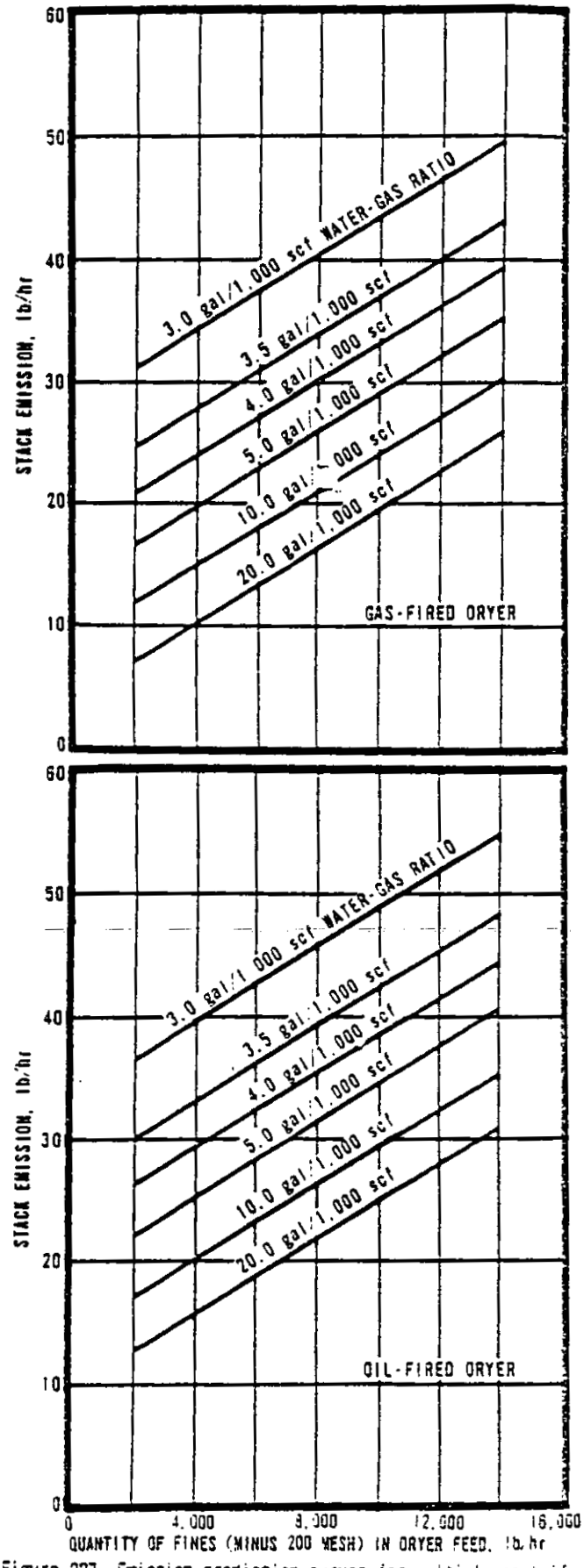


Figure 227. Emission prediction curves for multiple centrifugal scrubbers serving asphaltic concrete plants (Ingels et al., 1960).

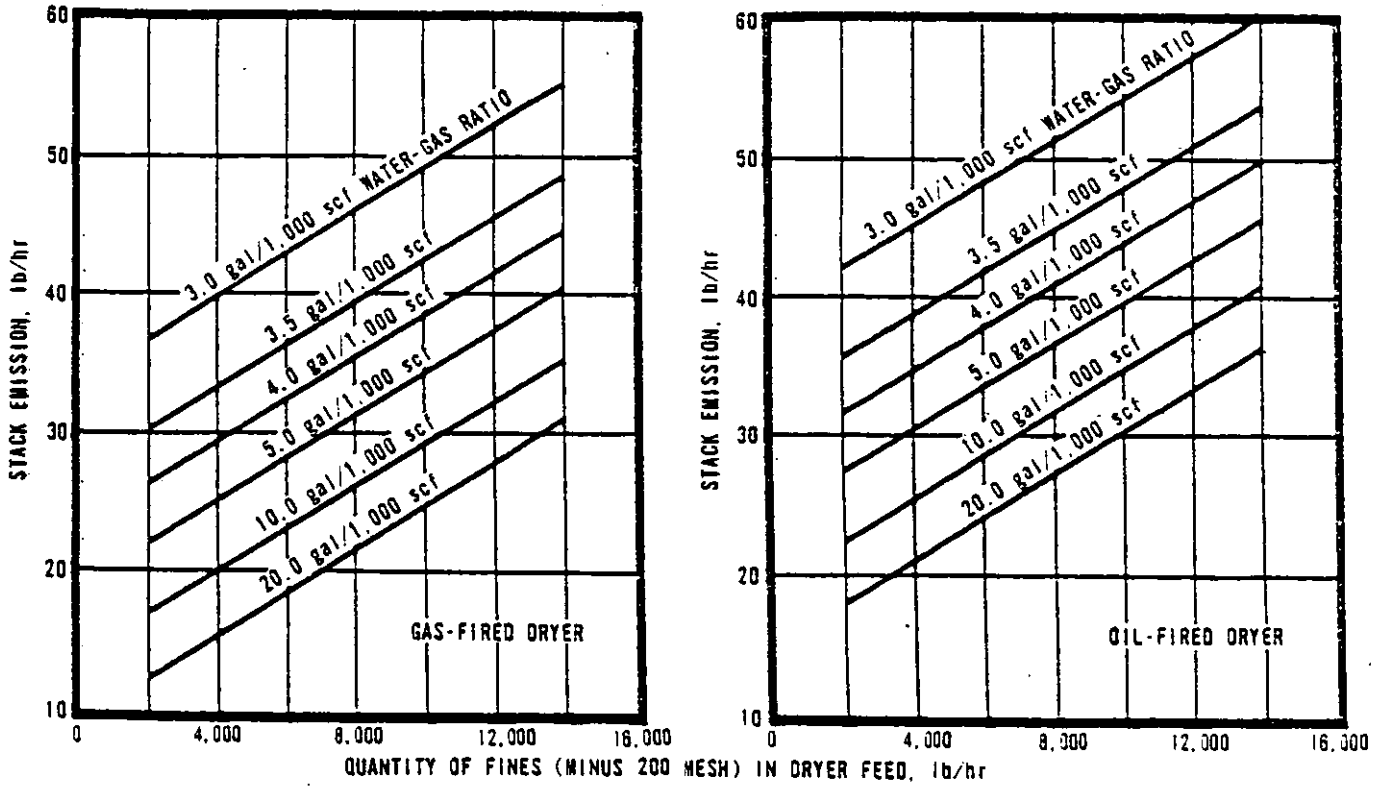


Figure 228. Emission prediction curves for baffled tower scrubbers serving asphaltic concrete plants (Ingels et al., 1960).

Collection efficiencies of a simple cyclone and a multiple cyclone for various particle sizes are shown in Table 96. Multiple cyclones achieve high efficiencies for particle sizes down to 5 microns, whereas single cyclones are very inefficient for particle sizes below 20 microns. The particle size data from this table are plotted on log-probability paper in Figure 229. This figure also shows the particle size distribution of the scrubber outlet. Other data on this installation have already been presented in Figure 222, test C-537.

Future Trends in Air Pollution Control Equipment

The air pollution control equipment discussed in this section has been adequate in the past for controlling dust emissions from hot-mix asphalt-paving batch plants in Los Angeles County. However, new regulations on dust emissions, adopted in January 1972, now require that more efficient devices than wet collectors be used as final collectors. The batch plants are now converting from scrubbers to baghouses.

Table 96. COLLECTION EFFICIENCY DATA FOR A CYCLONE AND A MULTIPLE CYCLONE SERVING A HOT-MIX PAVING PLANT

Dust particle size, μ	Test C-537 cyclone			Test C-537[a] multiple cyclone		
	Inlet, %	Outlet, %	Efficiency, %	Inlet, %	Outlet, %	Efficiency, %
0 to 5	6.2	19.3	13.3	19.3	37.0	77.1
5 to 10	9.4	31.9	5.4	31.9	34.0	91.7
10 to 20	13.8	31.6	36.1	31.6	8.3	97.3
20 to 50	22.9	15.1	31.6	15.1	9.2	99.9
50+	47.7	2.1	98.3	2.1	--	100.0
Dust loading lb/hr	5,463	1,525	72.1%	1,525	118.3	92.2%

[a]See Table 94, test C-537 for plant operating data.

(THESE DATA USED IN TABLE 3-10)

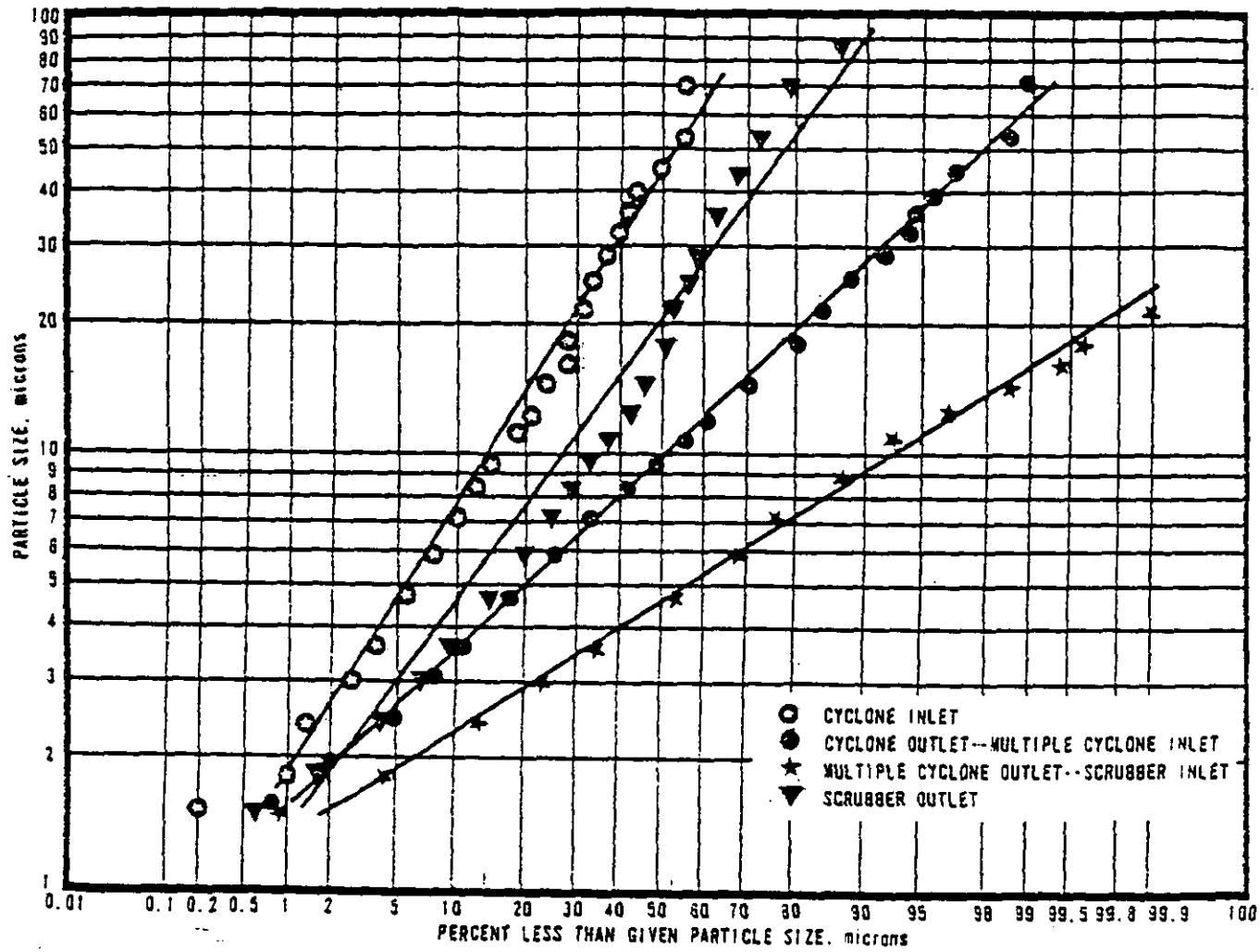


Figure 229. Plot of particle size of dust at the inlet and outlet of a cyclone and multiple cyclone from test C-537.

CONCRETE-BATCHING PLANTS

Concrete-batching plants store, convey, measure, and discharge the ingredients for making concrete to mixing or transportation equipment. One type is used to charge sand, aggregate, cement, and water to transit-mix trucks, which mix the batch en route to the site where the concrete is to be poured; this operation is known as "wet batching." Another type is used to charge the sand, aggregate, and cement to flat bed trucks, which transport the batch to paving machines where water is added and mixing takes place; this operation is known as "dry batching." A third type employs the use of a central mix plant, from which wet concrete is delivered to the pouring site in open dump trucks.

WET-CONCRETE-BATCHING PLANTS

In a typical wet-concrete-batching plant, sand and aggregates are elevated by belt conveyor or clam shell crane, or bucket elevator to overhead storage bins. Cement from bottom-discharge hopper trucks is conveyed to an elevated storage silo. Sand and aggregates for a batch are weighed by successive additions from the overhead bins to a weigh hopper. Cement is delivered by a screw conveyor from the silo to a separate weigh hopper. The weighed aggregates and cement are dropped into a gathering hopper and flow into the receiving hopper to the transit-mix truck. At the same time, the required amount of water is injected into the flowing stream of solids. Details and variations of this general procedure will be discussed later.

The Air Pollution Problem

Dust, the air contaminant from wet-concrete-batching, results from the material used. Sand and aggregates for concrete production come directly from a rock and gravel plant where they are washed to remove silt and clay-like minerals. They thus

APPENDIX E

REFERENCE 23

(not used in the development candidate emission factors)

ENTROPY
ENVIRONMENTALISTS, INC.

SPECIALISTS IN
SOURCE
SAMPLING

SOURCE SAMPLING REPORT

EXPERIMENTAL ASPHALT CONCRETE RECYCLING PLANT IN IOWA

68-01-3172

OCTOBER 1976

P. O. Box 12291, Research Triangle Park, North Carolina 27709
Phone 919-781-3550

INTRODUCTION

The asphalt concrete industry and state transportation agencies are looking at the feasibility of recycling old asphalt pavement in modified drum-mix drier plants. One such experimental plant located in Kosuth County, Iowa, has concerned the Iowa Department of Environmental Quality, due to previous observation of excessive visible emissions from a similarly operated plant. EPA Region VII was requested by the Iowa DEQ for technical assistance to determine if the plant was complying with the state air pollution regulations.

As part of its continuing study of new asphalt concrete technology trends and their impact on the Federal New Source Performance Standards, the Division of Stationary Source Enforcement of EPA agreed to provide assistance to the Iowa DEQ.

Source sampling was performed at the Everds Brothers, Inc. asphalt recycling plant located near Titonka, Iowa, on two separate occasions, under three different plant operating conditions.

Briefly, the first two conditions involved changes in the location of the recycled material injection. Only one set of simultaneous particulate tests at the inlet and outlet of the wet scrubber control equipment was made on September 29, 1976, because of problems encountered with the conveyor equipment used to introduce the recycled material midway in the drier. Three sets of simultaneous inlet-outlet particulate tests and one set of particle sizing tests were made on September 30 and October

1, 1976 (after process changes were made to feed all of the recycled asphalt material into the drier at the elevated end, along with the virgin material). In addition to the particulate tests, air samples before and after the scrubber were taken for a hydrocarbon analysis.

The last condition constituted a change in the type and rate of production of asphalt mix produced and an increase in the rotary drier's angle of elevation. The asphalt mix was changed from 66% recycled/34% gravel at a production rate of 185 to 204 tons per hour to 70% recycled/30% limestone at 245 to 250 tons per hour, while the drier slope was increased from 2° to 2.98° Three particulate tests were run at the separator outlet on October 6, 1976; three venturi-scrubber inlet particulate tests were performed on October 7, 1976 along with a set of inlet-outlet particle sizing tests.

During all the testing, water samples were taken at the scrubber water pump inlet and at the separator water discharge for a water analysis.

Present during the testing were Ronald Kolpa of the Iowa Department of Environmental Quality and Robert Farnham and Lee Binz from Barber-Greene Company, the manufacturers of the plant facility.

The measurements made for stack gas flow rates and particul emissions were made according to the Iowa Department of Environmental Quality's recommendations and generally followed the U.S Environmental Protection Agency's requirements. Due to the sampling problem of plugging filters encountered during the previous tests, a modified Method 8 sampling train was used in an

attempt to alleviate the problem.

Following sections of this report treat the summary of results, a brief descrition of the process and its operation, and the sampling and analytical procedures used.

SUMMARY OF RESULTS

The results of the particulate testing program are summarized and presented below in Table 1. The values used in computing the averages presented below were reasonably consisten considering the nature of the process and the control equipment.

Table 1

AVERAGE PARTICULATE CONCENTRATIONS

grains/dscf

Operating Conditions* #	Venturi Inlet			Separator Outlet		
	EPA 5 Only	EPA 5 + Impingers	Test Set #	EPA 5 Only	EPA 5 + Impingers	Correspon Table #'s
1	2.04	2.35	1	0.22	0.31	2-3
2	5.35	5.54	2-4	0.48	0.57	4-5
3	DNA	20.67	1-3	DNA	0.88	6-7

* See "Process Description and Operation" for details

Tables 2-7, as noted above, are summations of the individual test results from the particulate testing. Since a modified Method 8 sampling train was used in making the inlet-outlet tests during the third operating condition, no "EPA 5"results are available - a Method 8 train eliminates the filter between the probe and the water-filled impingers. For this reason, only "EPA + Impinger" results are presented in Tables 6 and 7, and in Table 1, under condition 3. Flow rate determinations for the scrubber outlet stack appear to be higher than real based on the calculated venturi-scrubber inlet flow rate. The higher value is probably due to non-parallel flow in the stack

(most probably tangential). Generally, the results would be lower than real due to sampling over isokinetically; however, due to the extremely small particle sizes as noted below, there probably was a negligible effect.

Results of the particle sizing tests on conditions two and three are given in Tables 8-11; no particle sizings were made under the first operating condition of the plant. During the second and third conditions, the aerodynamic diameter of 50% of the particles was less than the following sizes - second condition: inlet, 5.5 microns; outlet, 0.43 microns; third condition: inlet, 99% greater than 10 microns; outlet,7.1 microns.

Analysis for gaseous hydrocarbons on the air samples taken fro the venturi inlet and scrubber outlet during condition two resulted in values for the inlet only. The outlet bag samples developed a leak during shipment, resulting in dilutions and lower figures. By assuming the amount of carbon monoxide to be constant from the venturi inlet to the scrubber outlet, the total hydrocarbon content reported at the outlet was recalculated and found to be approximately the same as at the inlet. The inlet data was reported as follows: total hydrocarbons, 468 parts per million; methane, 18 parts per million; carbon monoxide, 2065 parts per million. On the total hydrocarbon measurement, an apparently very heavy hydrocarbon was present since the relative decay of a portion of the total was very slow. If heated lines were used to bring the sample from the stack directly into the instrument, the total hydrocarbon results might have been much higher.

Analysis of the water samples resulted in the values reported in Table 12. Because the analytical method used in determining the dissolved solids is designed for concentrations lower than those found, the results for the dissolved solids are questionable.

No visible emissions data was taken because of the nature of the steam dissipation in the plume. In general, however, the opacity was noted to be approximately 25-30%.

APPENDIX F

REFERENCE 26

U.S. DEPARTMENT OF COMMERCE
National Technical Information Service

PB-293 923

Fine Particle Emissions from Stationary and Miscellaneous Sources in the South Coast Air Basin. Final Report

KVB, Inc, Tustin, CA

Prepared for

California State Air Resources Board, Sacramento

Feb 79

TABLE 4-1. SUMMARY OF FIELD TEST RESULTS

Company/Industry Type	Test No.	Date	Sample Vol. DSCF	Sample Vol. NSCF	Sample Flow Rate NSCFM	Temperature, °F Stack	Temperature, °F Meter	Temperature, °F Oven	% Isokin.	Particulate Weights, mg Probe Catch	10 μ Cyclone	3 μ Cyclone	1 μ Cyclone	Filter Catch	Impinger H2O/Org.	Total
FUEL COMBUSTION																
Industrial Boiler	1S	9/13 1977	589	645	3.2	514	99	400	114		630.8	244.0	143.6	565.3	836 / 160.5	2580.2
	1J	9/13 1977	32	35	1.01	500	94	400	99.5		79.5	8.9	11.2	19.5	44.2 / 20.9	184.2
	2S	9/15 1977	917	101	3.72	515	106	401	138	54.2	256.3	234.9	349.1	275.6	390.9 / 139.1	1700.1
	2J	9/15 1977	81	90	.97	500	85	400	91	22.1	36.8	15.1	4.0	15.4	39.2 / 13.9	146.5
	3S	9/20 1977	570	625	3.47	516	101	400	122	63.7	268.8	116.7	126.9	277.3	1014.4 / 30.8	1898.6
	3J	9/20 1977	49	56	.93	500	88	369	79	26.4	36.7	3.1	3.5	18.7	24.1 / 4.3	116.8
	3BS	9/20 1977	62	70	1.17	500	100	305	99	36	-	-	-	124.4	63 / 43.6	267
	3A	9/20 1977	15	17	1.10	512	80	-	98	3.4 @ 7.5μm	3.4 @ 5.0μm	3.0 @ 3.5μm	1.2 @ 1.1μm	3.3	- / -	14.3
	16S	12/12 1977	807	883	3.68	450	88	301	118	20.2	34.6	9.6	6.3	100.1	883.8 / 10.5	1065.1
	16J	12/12 1977	229	263	1.10	450	100	300	119	2.8	2.7	3.1	8.2	24.2	87.0 / 1.0	129.0
IC Engine	07S	10/20 1977	634	762	3.2	412	91	100	88	13.2	8.4	2.8	1.3	29.8	1618.4 / 82.9	1756.8
IC Engine	07J	10/20 1977	207	243	1.156	412	90	196	103	5.5	3.6	1.4	1.2	1.2	192.7 / 62.7	268.3
IC Engine	15J	12/7 1977	227	240	1.00	720	78	400	93	37.0	26.5	9.2	35.3	89.9	142.6 / 143.8	484.3
Wood Boiler	05S	10/13 1977	418	451	5.66	305	106	388	124	30.0	126.2	514.8	100.0	346.7	2168.2 / 1041.4	4327.3

KVB 5806-783

TABLE 4-1 (cont'd.)

Test No.	Stack Flow Rate DSCFM	Excess O_2	CO_2	Sampling Time, min.	Plant Operation Time hr/yr	Emissions gr/DSCF	T/yr	lb/hr	lb/MBtu	Particle size distribution, Percent of Particles > 10μ	10-3μ	3-1μ	< 1μ	Control Type	Efficient	Remarks
						FUEL COMBUSTION										
1S	552	2.2		202.5		0.0672		0.320	0.0998	17	10	11	63	None		
1J	431	2.2		35		0.0896		0.331	0.1322	35	5	4	56	"		
2S	520	2.5		272		0.0285		0.128	0.043	8	11	15	66	"		
2J	520	2.5		92		0.0278		0.124	0.042	13	9	12	65	"		
3S	476	2.5		180		0.051		0.210	0.077	11	6	7	76	"		
3J	476	2.5		60		0.0365		0.149	0.549	36	4	2	58	"		
3BS	476	2.4		60		0.066		0.270	0.099	-	20	20	-	"		
3A	473	2.5		15		0.0179		0.073	0.0270	-	-	-	-	"		
16S	8181	8.37	9.0	240	8736	0.0203	6.2	1.43	0.0431	2.5	0.8	0.8	96	"		
16J	8181	8.37	9.0	240	8736	0.0087	2.7	0.61	0.0184	0.7	0.9	1.4	97	"		
7S	247	2.1	14.6	240	8736	0.0427	0.4	0.0906	0.0600	0.6	.15	0.35	99.1	None		
7J	247	2.1	14.6	211.2	8736	0.0200	0.2	0.0424	0.0281	0.8	0.4	0.6	98.4	"		
15J	5248	12.5	3.7	240	6570	0.0303	4.5	1.96	0.0995	4	2	2	92	"		1450 kW
5S	5966	16.6	4.3	130	8736	0.159	35.7	8.17	0.214	0.3	4.45	4.45	74	None		

TABLE 4-1 (cont'd.)

Company/Industry Type	Test No.	Date	Sample Vol. DSCF	Sample Vol. NSCF	Sample Flow Rate NSCFM	Temperatures, °F Stack	Temperatures, °F Meter	Temperatures, °F Oven	Δ Impin.	Particulate Weights, mg Probe Catch	10 μ Cyclone	3 μ Cyclone	1 μ Cyclone	Filter Catch	Impinger H2O/Org.	Total
Utility Boiler #1	11S	11/14 1978	943	1027	4.3	275	91	406	158	29.5	28.3	13.9	10.6	98.4	325.7 50.4	556.8
Utility Boiler	11J	1/14 1978	223	245	1.02	275	81	389	164	11.7	14.4	3.4	2.6	24.8	26.1 29.6	112.6
"	12S	1/14 1978	915	996	4.1	284	94	392	155	31	31.2	25.3	9.6	96.8	215.7 19.4	429.0
"	12J	1/16 1978	222	244	1.01	275	81	389	156	3.6	14.3	2.6	2.7	24.6	25.7 10.4	83.9
"	13S	1/18 1978	1406	1533	4.2	281	82	388	149	92.2	19.8	64.8	3.0	183.4	2107.8 0	2471.0
"	13J	1/18 1978	300	316	1.06	273	77	345	132	4.0	3.5	0	0.9	29.8	122.2 10.2	170.6
"	23S	1/24 1978	899	977	4.24	297	80	390	76	157.1	35.6	29.2	5.7	116.9	1174.3 167.2	1686.0
"	23J	1/24 1978	194	214	0.93	290	80	355	87	10.6	10.9	1.2	3.6	25.5	47.3 6.5	105.6
"	24S	1/26 1978	946	1024	4.2	222	111	400	77	30.4	41.7	3.4	1.4	96.8	495.0 17.4	686.1
"	24J	1/26 1978	212	233	0.98	220	95	299	88	18.5	5.8	1.5	0.9	24.5	106.6 409	198.7
"	32S	3/6 1978	772	852	4.1	295	84	377	92	49.7	26.9	6.7	3.4	64.5	407.5 62.4	621.1
"	32J	3/6 1978	778	851	1.03	292	79	351	92	83.3	5.5	35.1	11.4	68.0	195.9 34.4	433.6
"	33S	3/8 1978	883	981	4.1	286	75	385	100	73.9	52.6	28.4	6.9	108.3	427.1 60.0	757.2
"	33J	3/8 1978	227	249	1.06	286	79	383	101	21.1	19.4	3.8	7.0	29.5	60.1 54.9	195.8

TABLE 4-1 (cont'd.)

Test No.	Stack Flow Rate DSCFM	Excess O_2	CO_2	Sampling Time, min.	Plant Operation Time hr/yr	Emissions gr/DSCF	T/yr	lb/hr	lb/MMBtu	Percent of Particles >10μ	10-3μ	3-1μ	<1μ	Control Type	Control Efficient	Remarks
11S	833730	4.8	10.0	240	8736	0.0091	284	65.03	0.0154	3.0	2.5	2	91.5	None		472 MW
11J	833730	4.8	10.0	240	8736	0.0078	243	55.6	0.0132	9	3	10	78	"		
12S	898170	5.9	10.0	240	8736	0.0072	242	55.5	0.0130	4	5	7	84.0	"		476 MW
12J	898170	5.9	10.0	240	8736	0.0058	196	44.8	0.0105	9	3	8	80.0	"		
13S	913230	6.2	10.5	360	8736	0.0271	928	212.4	0.050	0.1	0.9	3	95.5	"		472 MW
13J	913230	6.2	10.6	316	8736	0.0088	299	68.5	0.0162	2	0	0	98	"		
23S	849434	6.4	10.5	230.5	8736	0.0289	921	210.8	0.0554	1.5	1.3	2.2	95	None		450
23J	849434	6.4	10.5	229.6	8736	0.0084	268	61.3	0.0161	10	1.0	1.5	87.5	"		
24S	481016	6.5	10.0	240	8736	0.0112	202	46.2	0.0214	5	1	1	93.0	"		238
24J	481016	6.5	10.0	240	8736	0.0144	259	59.3	0.0275	5.5	0.5	0.6	96.5	"		
32S	79598	4.75	10.2	206.9	8736	0.0124	369	84.5	0.0211	3.5	1.5	1	94	"		453
32J	79598	4.75	10.2	828.5	8736	0.0086	256	58.7	0.0147	0.1	0.7	4	95	"		
33S	85504	6.0	10.7	240	8736	0.0132	423	96.9	0.0244	4	4	5	87	"		455
33J	85504	6.0	10.7	238.6	8736	0.0133	427	97.7	0.0246	8	2	2	88	"		

TABLE 4-1 (cont'd.)

Company/Industry Type	Test No.	Date	Sample Vol. DSCF	Sample Vol. NSCF	Sample Flow Rate NSCFM	Temperature, °F Stack	Temperature, °F Meter	Temperature, °F Oven	Δ Inches	Particulate Weights, mg Probe Catch	10 μ Cyclone	1 μ Cyclone	1 μ Cyclone	Filter Catch	Impinger H_2O/Org.	Total
Utility Boiler #2	218	1/16 1978	774	853	4.6	274	76	399	150	60.6	4.3	4.8	1.9	50.9	271.6 66.6	460.7
"	21J	1/16 1978	157	177	1.00	275	72	382	131	11.2	1.2	0.6	0.9	12.2	45.9 0.4	72.4
"	228	1/18 1978	1138	1233	4.38	225	83	381	111	18.0	7.3	37.3	9.8	82.7	619.0 34.1	808.2
"	223	1/18 1978	250	277	0.994	225	83	370	100	8.4	2.0	1.7	2.8	19.5	33.0 8.4	75.8

TABLE 4-1 (cont'd.)

Test No.	Stack Flow Rate DSCFM	Excess O_2, %	CO_2, %	Sampling Time, min.	Plant Operation Time hr/yr	Emissions gr/DSCF	Emissions T/yr	Emissions lb/hr	Emissions lb/MMBtu	Percent of Particles >10μ	Percent of Particles 10-1μ	Percent of Particles 1-1μ	Percent of Particles <1μ	Control Type	Control Efficient	Remarks
21S	378394	7.0	9.8	185	8736	0.0092	130.2	29.8	0.022	.5	0.75	1.6	97.5	None		
21J	378394	7.0	9.8	176	8736	0.0071	100.9	23.0	0.017	1.2	0.6	0.7	97.5	"		
22S	215124	8.0	9.5	281	8736	0.0109	88.6	20.2	0.023	0.1	1.1	5.8	93	"		
22J	215124	8.0	9.5	279	8736	0.0046	37.7	8.6	0.0099	1.4	1.1	1.5	96	"		

TABLE 4-1 (cont'd.)

Company/Industry Type	Test No.	Date	Sample Vol. DSCF	Sample Vol. NSCF	Sample Flow Rate NSCFM	Temperature, °F Stack	Temperature, °F Meter	Temperature, °F Oven	Δp Inches	Particulate Weights, mg Probe Catch	10 μ Cyclone	3 μ Cyclone	1 μ Cyclone	Filter Catch	Impinger H_2O/Org.	Total
							MINERAL									
Gypsum	6S	10/18 1977	385	507	4.83	414	104	404	131	32.3	565.5	506.4	80.2	33.6	145.0 32.5	1395.5
Brick	8S	11/3 1977	699	701	4.91	85	95	202	94	15.5	130.9	12.8	1.7	1.6	39.5 89.0	291.0
Brick	8J	11/3 1977	115	117	0.98	75	89	205	51	105.4	8581.5	14.9	5.2	2.5	3.5 0	8713.0
Cement	9S	11/7 1977	942	985	3.99	365	94	395	132	31.5	98.5	124.9	34.3	19.5	32.6 1.4	342.7
Cement	18S	12/16 1977	940	992	4.13	381	92.3	398	89.5	35.4	145.9	185.1	53.8	27.6	151.7 6.9	606.4
Glass	20S	1/12 1978	990	1062	5.14	420	89.7	389	145	5.6	7.3	4.1	5.4	12.7	359.3 2.1	396.5
Glass	20J	1/12 1978	194	217	0.97	1001	76	374	90	7.5	5.6	2.4	111.1	264.7	56.8 9.4	457.5
Glass	28S	2/16 1978	325	361	3.6	819	93	397	81	75.4	13.3	12.1	34.7	947.6	191.5 19.1	1293.7
Glass	35S	3/16 1978	370	410	3.7	835	100	388	94	48.4	90.2	49.0	82.3	938.4	192.7 16.7	1425.7
Glass	35J	3/16 1978	170	186	0.94	835	118	397	110	54.4	24.8	16.9	256.9	181.0	134.1 47.5	715.6
Fiberglass	38S	3/28 1978	915	963	3.8	154	104	399	105	13.2	7.6	2.2	3.1	120.8	820.6 43.9	1011.4
Fiberglass	38J	3/28 1978	230	241	0.96	154	103	379	101	11.3	1.4	1.4	3.5	30.8	141.6 13.7	203.7
Asphalt Roofing	25S	1/31 1978	991	996	4.15	130.8	94	388	102	25.6	19.3	18.7	5.1	2.2	64.5 349.7	485.0
Asphalt Roofing	25J	1/31 1978	234	239	0.99	139	85	249	109.5	8.8	3.1	1.4	1.7	0	11.9 91.2	118.1
Batch	29S	2/21 1978	834	931	3.9	175	92	400	113	18.3	261.2	15.2	8.7	15.0	65.2 37.0	420.6
Batch	29J	2/21 1978	76	92	0.85	186	86	244	108	804.7	30931.8	10928.3	2182.9	12112.1	3.1 3.6	56966.5

TABLE 4-1 (cont'd.)

Test No.	Stack Flow Rate DSCFM	Excess O_2	CO_2	Sampling Time, min.	Plant Operation Time hr/yr	Emissions gr/DSCF	T/yr	lb/hr	lb/MMBtu	Percent of Particles >10μ	10-3μ	3-1μ	<1μ	Control Type	Control Efficient	Remarks
						MINERAL										
6S	4508	19.0	0.5	105	8736	0.0558	9.4	2.16	NA	12	31.5	34	22			
8S	6435	Air	--	145.2	2475	0.00641	0.4	0.354	NA	44	4	4	48	Bag-house	99.8	Baghouse Exit
8J	2139	Air	--	120	2475	1.169	26.6	21.5	NA	98.6	0.85	0.30	0.15	"	99.8	Inlet
9S	12152	14.2	7.2	240	7728	0.00560	22.6	5.85	NA	8.0	32	40	20	Not	Tested	Fuel - gas
18S	14612	14.3	10.4	240	7728	0.00993	48	12.47	NA	8.0	24	34	34.0	Not	Tested	Fuel - coal
20S	34959	12.7	5.8	240	8736	0.00617	8.0	1.83	NA	1.4	0.6	1	97	ESP	98.24 Solids only	ESP Outlet
20J	27484	12.3	5.9	223	8736	0.0364	37	8.59	NA	0.5	0.4	0.5	98.6	ESP	98.24	ESP Inlet
28S	13670	8.6	6.5	90.1	8400	0.0612	30.2	7.19	NA	0.6	0.7	1.3	97.4	None		
35S	11888	11.0	8.0	100	8400	0.0594	25.5	6.06	NA	4.2	3	4	88	None		
35J	11888	11.0	8.0	180	8400	0.0649	27.8	6.63	NA	1.2	1.3	2	95	None		
38S	65779	20.0	0.5	240	8736	0.0170	84.0	19.24	NA	0.6	0.2	0.2	98.9	Water curtain	Not Tested	Emissions given for both ducts
38J	65779	20.0	0.5	240	8736	0.0136	67.2	15.4	NA	0.2	0.2	0.4	99.2			
25S	45349	6.4	0.4	240	7072	0.00754	10.4	2.94	NA	2.3	2.8	4	91	Mist Eliminator	Not Tested	
25J	44697	6.4	0.4	240	7072	0.0079	10.5	2.98	NA	0.55	0.2	0.3	99	"	"	
29S	65089	18.2	3.5	210	720	0.00770	1.56	4.34	NA	60	6	4	30	Bag-house	99.9	
29J	50557	17.4	2.0	90	720	11.405	2079.9	5777.5	NA	--	--	--	--			

TABLE 4-1 (cont'd.)

Company/Industry Type	Test No.	Date	Sample Vol. DSCF	Sample Vol. MSCF	Sample Flow Rate MSCFM	Temperature, °F Stack	Temperature, °F Meter	Temperature, °F Oven	% Isokin.	Particulate Weights, mg Probe Catch	10 μ Cyclone	3 μ Cyclone	1 μ Cyclone	Filter Catch	Impinger H_2O/Org.	Total
						FOOD AND AGRICULTURE										
Rice	4S	10/11 1977	973	996	5.00	87	100	202	117	37.5	327.8	64.9	7.6	1.0	57.6 / 94.3	590.7
Rice	4J	10/11 1977	190	197	0.99	86	91	205	116	36.6	141.1	2.2	1.0	0.7	6.8 / 1.9	190.3
CARACOA	3JS				Lost	Sample	Due	To	High	Temperature						
CARACOA	3JJ	3/23 1978	232	241	0.99	115	101	400	122	180.3	304.9	1.0	8.1	2.1	119.3 / 174.1	1069.8
						METAL FABRICATION										
Heat Treat Steel	14S	11/29 1977	762	772	4.06	139	114	397	84	16.5	12.5	14.8	9.7	10.2	59.6 / 16.8	140.1
Heat Treat Steel	14J	11/29 1977	178	180	0.97	180	117	391	97	59.2	96.7	73.7	261.8	147.2	10.2 / 36.2	685.0
Sand Blast Steel	34S	3/14 1978	936	941	4.0	75	103	399	100	0.2	14.2	3.1	1.0	1.2	13.2 / 20.4	53.3
Sand Blast Steel	34J	3/14 1978	164	164	1.03	66	85	351	117	61.3	9852.8	262.4	186.6	17.3	5.8 / 60.3	20446.5
						METALLURGICAL										
Aluminum Foundry	10S	11/10 1977	1220	1341	4.30	1141	105	404	81	57.0	12.1	8.4	5.1	47.0	51.1 / 27.7	208.4
Aluminum Foundry	10J	11/10 1977	334	383	1.22	1141	97	382	69	12.0	4.3	1.0	4.0	6.6	2.2 / 15.7	45.8
Sinter Plant	26S	2/2 1978	954	1023	4.2	229	87	376	108	35.1	85.1	36.7	14.1	100.3	2345.2 / 224.5	2841.0
Sinter Plant	26J	2/2 1978	206	223	0.99	245	82	339	122	727.8	142.4	28.9	339.3	1180.4	180.4 / 135.9	2735.1
Open Hearth Steel	36S	3/21 1978	698	181	3.8	422	107	402	93	373.1	70.3	66.1	161.0	251.1	722.8 / 16.0	1660.4
Open Hearth Steel	36J	3/21 1978	170	189	0.96	486	101	403	98	227.9	268.9	99.1	585.2	883.3	165.0 / 54.0	2283.4

TABLE 4-1 (cont'd.)

Test No.	Stack Flow Rate DSCFM	Excess O_2 %	CO_2 %	Sampling Time, min.	Plant Operation Time hr/yr	Emissions gr/DSCF	Emissions T/yr	Emissions lb/hr	Emissions lb/MMBtu	Percent of Particles > 10μ	Percent of Particles 10-1μ	Percent of Particles 1-1μ	Percent of Particles < 1μ	Control Type	Control Efficient	Remarks
						FOOD AND AGRICULTURE										
4S	124901	16	--	199.2	700	0.00935	3.5	10.03	NA	46	12	12	30	--	screens not tested	
4J	124901	16	--	198.9	700	0.0154	5.8	16.5	NA	89	2	1	8	--	--	
37S														after lost	burner test	
37J	1620	Air	--	233	2000	0.0711	2.0	2.0	NA	41	1	1	57	--	--	
						METAL FABRICATION										
14S	45196	Air	--	190	4080	0.00283	2.2	1.10	--	4	8	14	74	Bag-house	90%	Exit
14J	20767	Air	--	190	4080	0.0593	21.6	10.58	--	5	7	10	76	Bag-house	90%	Inlet
34S	16623	Air	--	233	1040	0.00088	0.07	0.125	--	23	6	6	74	Bag-house	99.9	Baghouse Exit
34J	11577	Air	--	159	1040	1.922	99.4	191.2	--	93	3.5	1.7	1.8			Baghouse Inlet
						METALLURGICAL										
10S	3186	5.7	6.8	314.1	4774	0.00263	0.17	0.072	NA	5	4	5	86	None		
10J	3186	5.7	6.8	304.1	4774	0.00211	0.14	0.058	NA	9.5	3	2	86			
26S	118768	16.3	4.4	240	8320	0.0459	195	46.82	NA	2	1.2	1.4	95	BH	97.8 solids only	Baghouse Exit
26J	96855	15.8	5.0	225	8320	0.205	709	170.4	NA	6	1	1	92	BH	97.8 solids only	Baghouse Inlet
36S	17551	9.5	10.5	181	8064	0.0366	22.3	5.53	--	2.2	3.8	7	87.5	ESP	84.2	ESP Exit
36J	19791	8.5	11.5	177	8064	0.206	141.4	35.08	--	8	3	4	82		90.3 solids only	EST Inlet

TABLE 4-1 (cont'd.)

Company/Industry Type	Test No.	Date	Sample Vol. DSCF	Sample Vol. NSCF	Sample Flow Rate NSCFM	Temperature, °F Stack	Temperature, °F Meter	Temperature, °F Oven	% Isokin.	Particulate Weights, mg Probe Catch	10 μ Cyclone	3 μ Cyclone	1 μ Cyclone	Filter Catch	Impinger H_2O/Org.	Total
						ORGANIC SOLVENT USE										
Spray Booth	27S	2/14 1978	800	817	4.1	68	88	234	103	76.7	41.5	5.2	7.6	8.1	9.0 44.5	192.6
Spray Booth	27J	2/14 1978	189	197	0.99	68	88	233	106	11.0	2.0	4.9	8.1	0.8	6.0 7.1	39.9
Spray Booth	31S	2/28 1978	945	956	3.99	71	90	249	102	49.8	6.6	2.8	6.2	4.8	21.2 60.9	152.3
Spray Booth	31J	2/28 1978	235	239	0.99	71	86	260	104	20.4	3.0	2.8	1.1	0	4.0 11.7	43.0
						CHEMICAL										
Boric Acid	17S	12/14 1977	948	966	4.03	132	111	400	95	70.5	153.8	5.5	3.6	2.6	1213.7 10.4	1460.1
Boric Acid	17J	12/14 1977	50	52	0.95	136	95	370	231	1301.5	114.2	0.6	1.5	0.8	569.2 11.9	1999.7
Fertilizer Plant	19S	1/5 1978	956	975	5.02	118	90	198	113	3.4	8.1	1.6	0.5	0.3	148.2 11.4	173.5
Fertilizer Plant	19J	1/5 1978	196	201	1.03	147	85	202	91	27.5	8980.9	0.4	0.5	0.7	81.1 22.7	9113.8
						WOOD PROCESSING										
Sanding	30S	2/24 1978	765	773	4.01	78	94	80	94	13.4	10.1	2.6	0.8	2.2	24.8 55.4	109.3
Sanding	30J	2/24 1978	125	126	1.05	78	75	76	82	49.6	32.3	21.3	23.8	0.7	3.9 4.2	135.8
Sanding	30 &5	2/24 1978	64	69	1.01	77	78	78	130	235.4	3365.3	--	--	230.6	18.2 4.5	3854.0
Resawing	39S	3/31 1978	977	988	4.17	75	83	66	108	41.0	110.9	14.5	--	1.9	13.0 19.9	201.2
Resawing	39J	3/31 1978	93	98	0.83	75	92	70	59	699.1	1504.7	2.3	4.5	--	1.5 5.3	2217.4
						PETROLEUM										
Heaters	40S	4/4 1978	916	1044	3.8	460	88	407	117	21.6	14.8	5.6	4.4	1.5	147.1 57.2	252.4
FCC Unit	41S	4/10 1978	861	962	4.01	525	98	308	91	1293.6	758.5	93.1	132.5	52.8	684.5 63.3	3070.1

TABLE 4-1 (cont'd.)

Test No.	Stack Flow Rate DSCFM	Excess O_2	CO_2	Sampling Time, min.	Plant Operation Time hr/yr	Emissions gr/DSCF	T/yr	lb/hr	lb/MMBtu	Percent of Particles >10μ	10-1μ	1-1μ	<1μ	Control Type	Control Efficient	Remarks
						ORGANIC SOLVENT USE										
27S	91400	Air	--	199	4000	0.00371	5.8	2.91	NA	32	5	5	59	--		
27J	91400	Air	--	199	4000	0.00325	5.1	2.56	NA		4.4	15		--		
31S	235,400	Air	--	240	2750	0.00240	6.9	5.0	NA	5	2.5	3	90			
31J	235,400	Air	--	240	2750	0.00282	7.8	5.7	NA	5	3	8	83			
						CHEMICAL										
17S	10948	20.9	--	240	8736	0.0237	9.74	2.23	--	10	0.5	0.5	89	BH	97.5	Baghouse Exit
17J	16903	20.9	--	55	8736	0.6105	389	88.7	--	15	1	0	84	BH	97.5	Inlet
19S	4688	Air	--	193	2000	0.00280	0.1	0.11	--	4	1	1	94	BH	99.1	Baghouse Exit
19J	1979	Air	--	195	2000	0.7154	12.2	12.16	--	98.6	0.2	0	1.2	BH	99.1	Inlet
						WOOD PROCESSING										
30S	4179	Air	--	192.3	2080	0.0022	0.1	0.078	NA	8	3	3	86	BH	96.3	Baghouse Exit
30J	4206	Air	--	120	2080	0.0168	0.6	0.601	NA	37	4	12	36	--		Baghouse Inlet, Cyclone Exit
30 #5	4384	Air	--	70	2080	0.931	36.5	35.05	NA	--	--	--	--	Cyclone	98.4	Cyclone Inlet
39S	6546	Air	--	240	2080	0.00317	0.2	0.2	--	60	11	9	20	Cyclone	99.0	Cyclone Outlet
39J	6703	Air	--	120	2080	0.366	21	20.0	--	99	0.3	0.3	0.7	"	99.0	Cyclone Inlet
						PETROLEUM										
40S	16216	3.9		240	8736	0.00424	2.6	0.59	0.0062	4.5	2	1.5	91	None		
41S	31399	0.9	10.7	240	8400	0.055	62.33	14.84	--	62	5	5	52	ESP	Not Tested	

4.2.12 Asphaltic Concrete Batch Plants

A. Process Description (Ref. 4-20 & 4-21)--

Plants produce finished asphaltic concrete through either batch or continuous aggregate mixing operations. Different applications of asphaltic concrete require different aggregate size distributions, so that the raw aggregates are crushed and screened at the quarries. The coarse aggregate usually consists of crushed stone and gravel, but waste materials, such as slag from steel mills or crushed glass, can be used as raw material.

As processing for either type of operation (batch or continuous) begins, the aggregate is hauled from the storage piles and placed in the appropriate hoppers of the cold-feed unit. The material is metered from the hoppers onto a conveyor belt and is transported into a gas or oil-fired rotary dryer.

As it leaves the dryer, the hot material drops into a bucket elevator and is transferred to a set of vibrating screens where it is classified by size into as many as four different grades. At this point it enters the mixing operation.

In a batch plant, which was the type tested in this program, the classified aggregate drops into one of the four large bins. After all the material is weighed out, the sized aggregates are dropped into a mixer and mixed dry for about 30 seconds. The asphalt, which is a solid at ambient temperatures, is pumped from heated storage tanks, weighed, and then injected into the mixer. The hot, mixed batch is then dropped into a truck and hauled to the job site. Figure 4-48 illustrates a batch plant similar to the one tested and indicates the location of particulate sources in the operation. There are many sources of fugitive particulate emissions as shown in the sketch. In this program the ducted emissions controlled by a baghouse were characterized, as were the partially controlled emissions entering the baghouse.

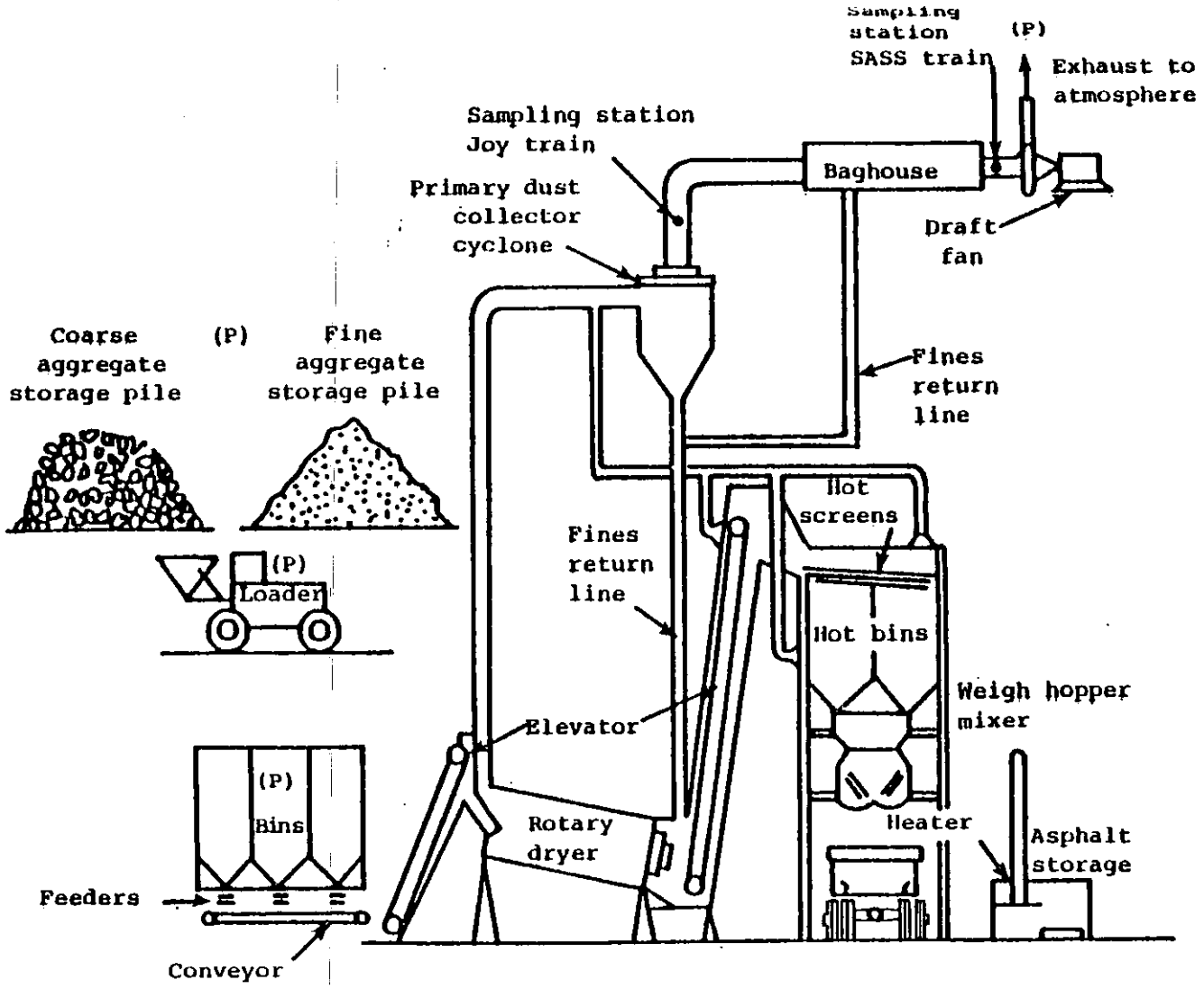


Figure 4-48. Batch hot-mix asphalt plant. "P" denotes particulate emission points.

KVB 5806-783

B. Particulate Test Set-up--

Two trains were used simultaneously to sample the inlet and outlet of the baghouse. The inlet station was located on the vertical duct approximately 12 ft ahead of the bend entering the baghouse. The velocity profile of the inlet duct was taken through the three 3" diameter ports provided. The velocity profile in the inlet and exit ducts of the baghouse are listed in Table 4-58.

The outlet sample station was located on the horizontal section of the duct about eight ft upstream of the fan. In the interest of the safety of the crew, the velocities were not taken through the vertical port. Therefore Velocity Points 10 through 15 were obtained by swinging the pitot tube. A 7/16" nozzle was used at Velocity Point #3 on the outlet duct and a 5/16" nozzle was used at Point #3 of the inlet duct.

C. Particulate Test Results--

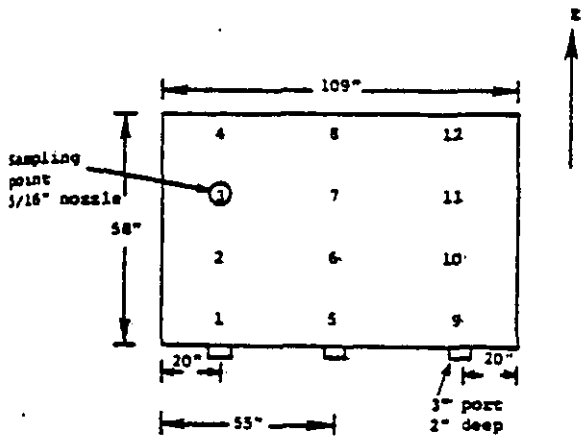
The results of the two tests (Test 29S and 29J) discussed in this section are listed in Table 4-1. Elemental composition, sulfate, nitrate, and carbon analysis were determined for all fractions of particulate catches which contained weights in excess of 100 mg. The details for these procedures are discussed in Section 3.2.2. Due to the very heavy loading on the inlet side of the baghouse, the cyclones and filter in the small sampling train had filled to total capacity and caused a pressure drop during sampling which resulted in stopping the sampling.

D. Discussion of Test Results--

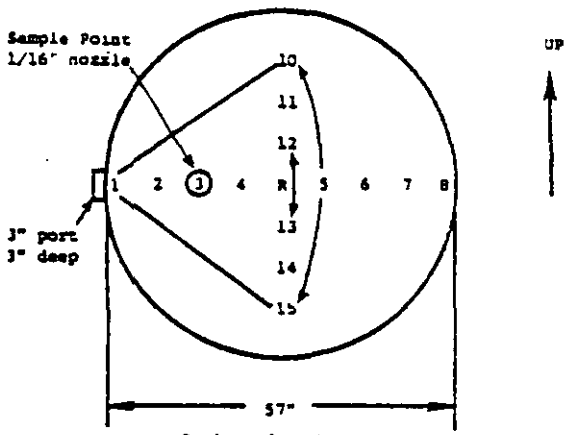
1. Efficiency of the baghouse--Using the solid catch data (i.e. without the impinger catch) from both sampling trains for the inlet and exit, the baghouse efficiency was calculated to be 99.95%. Using the total catch, the efficiency would be 99.92%.

2. Particle size distribution--Figure 4-49 is a plot of particle size (μm) vs accumulated weight percent, the latter plotted on a probability scale as explained in Section 3.2.3 B. Two sets of curves are presented, one including the impinger catch, the other ignoring it. Considering the large amount of material collected upstream of the filter, it would seem that the

TABLE 4-58.. VELOCITY PROFILE--ASPHALT BATCH PLANT (TEST 29)



Inlet to Baghouse
Temperature: 160°F
Static Pressure: -4.5" H_2O



Outlet of Baghouse
Temperature: 160°F
Static Pressure: -11" H_2O

Distance from End of Port	Velocity Point #	Velocity ft/sec
8"	1	30.2
20"	2	30.2
32"	3	34.1
44"	4	37.2
8"	5	31.9
20"	6	36.7
32"	7	38.2
44"	8	41.8
8"	9	37.2
20"	10	34.1
32"	11	28.9
44"	12	28.3

Average: 34.1 ft/sec

75337 scf

Distance from End of Port	Velocity Point #	Velocity ft/sec
5"	1	68.8
9-3/8"	2	76.3
14-5/8"	3	85.3
22-3/8"	4	85.3
33"	R	95.4
43-5/8"	5	95.4
51-3/8"	6	85.3
56-5/8"	7	85.3
61"	8	81.0
37"	10	95.4
35"	11	81.0
34"	12	89.5
34"	13	85.3
35"	14	73.9
37"	15	68.8

Average: 84.6 ft/sec

75354 scf

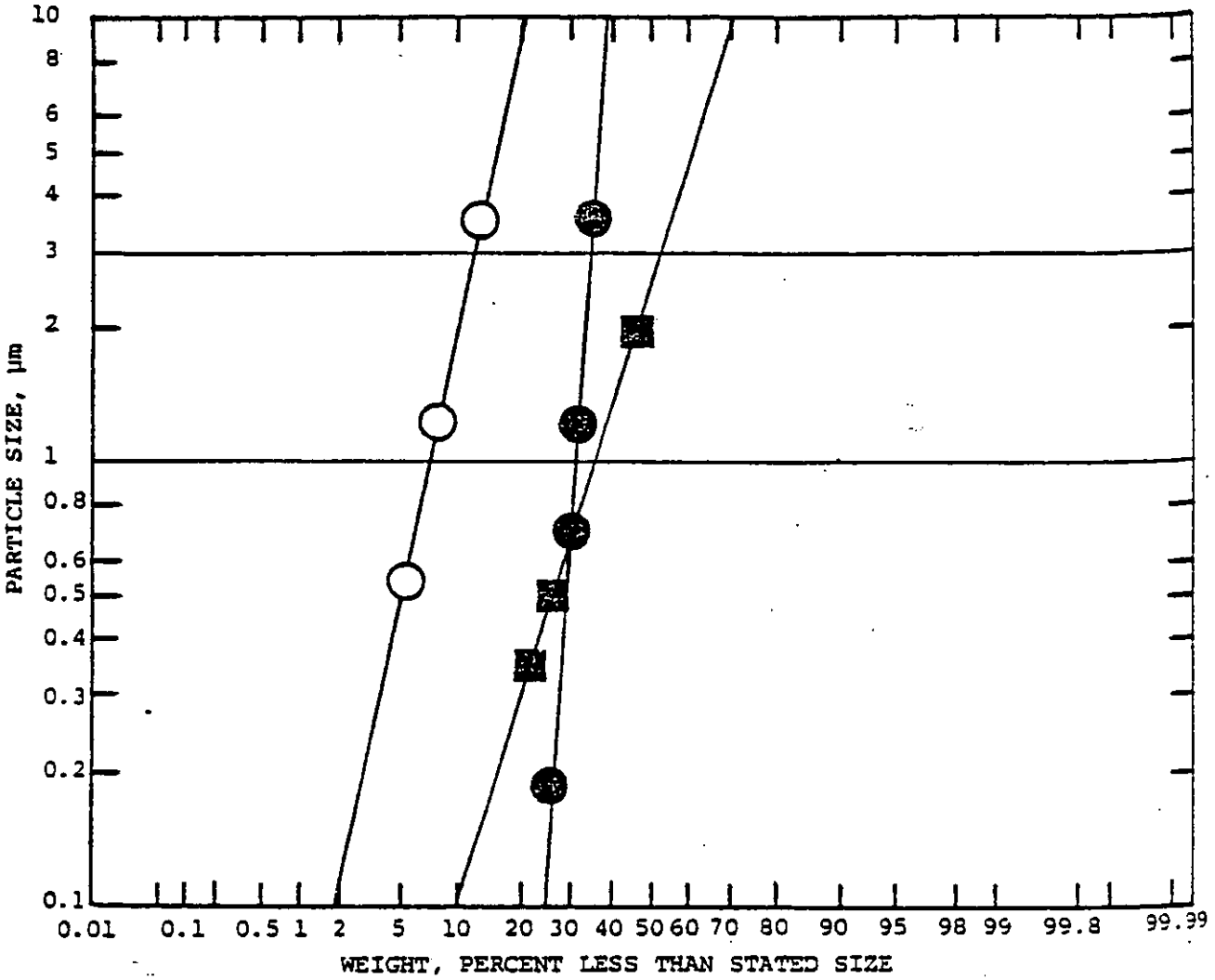


Figure 4-49. Particle size distribution for asphaltic concrete batch plant (Test 29)

effects of pseudo particulates would be insignificant. Therefore, the impinger catch was believed to be properly included in the measurements of the suspended particulates from asphaltic concrete plants. As a result of the filling of the cyclones in the Joy train, a particle size distribution curve could not be made. It is estimated from visual examinations that the mean particle size for the inlet is greater than 100μm. The breakdown of the particle size distribution for the baghouse outlet including the impinger is as follows:

	Percent of Particles			
	Greater than 10μm	10-3μm	3-1μm	Less than 1μm
Test 29S	60	6	4	30

(These Data Reproduced in Table 3-11)

The mean particle size for the baghouse outlet is approximately 60μm. Although the baghouse has a high efficiency some of the coarser particles still penetrate, no doubt due to small leaks in and around the bags.

3. Chemical composition of particulates--Table 4-59 lists the results from the chemical analysis of the particulate fraction for the tests discussed in this section. Although silicon is not detected with XRF (see Section 3.2.2 B), it is clear that silicon is the most abundant element in these samples. The unanalyzed portion of Table 4-59 is primarily SiO_2 and other compounds of silicon.

4. Emissions and emission factors--Emissions and emission factors can be listed with several different units. The following lists some of these emissions and factors for these tests:

Units	Controlled Test 29S	Uncontrolled Test 29J
gr/DSCF	0.00776	11.485
T/yr	1.56	2079.9
lb/hr	4.34	5777.5
lb/ton produced	0.02	34
lb/ton produced (Ref. 4-22)	0.1	45

TABLE 4-59. CHEMICAL COMPOSITION OF PARTICULATE SAMPLES IN PERCENT FOR ASPHALT BATCH PLANTS (TEST 29)

SAMPLE #	10μm Cyclone 29S-2S	Filter 29S-5S	10μm Cyclone 29J-2S
WT. PERCENT OF CUT	62.1	3.57	54.3
XRF ANALYSIS			
Arsenic	t		
Barium	t		t
Calcium	2.4/0.3	10/3	1.9/0.3
Chromium	t		t
Iron	3.6/0.5	1/0.1	4.3/0.5
Potassium	1.5/0.5		1.5/0.2
Silver	t		
(Sulfur)	(<8)	(<4)	(<3)
Titanium	t	t	t
TOTAL[1]	8	11	8
Sulfates, H_2O sol[2]	2		
(Sulfur, from SO_4^-)[4]	(t)		
Nitrate (H_2O sol)[2]	t		
Total Carbon[3]			t
(Volatile Carbon)[3]			
(Carbonates)[3]			(t)
TOTAL ANALYZED	10	11	8
BALANCE	90	89	92
	100%	100%	100%

t detected in concentration of <1%

1 analyzed by x-ray fluorescence--Section 3.2.2 B

2 analyzed by wet chemistry--Section 3.2.2 A

3 analyzed by Oceanography carbon analyzer--Section 3.2.2 A

4 calculated from sulfates (sulfur=sulfate/3) to compare with sulfur from XRF

5 for values shown as X/Y, X is % of the element present and Y is the error (i.e. X% ± Y%)

( ) not included in total--sulfur and sulfates are accounted for in sulfur XRF analysis and volatile carbon and carbonate are accounted for in total carbon

APPENDIX G

REFERENCE 27

CHARACTERIZATION OF INHALABLE PARTICULATE MATTER EMISSIONS FROM A DRUM-MIX ASPHALT PLANT

by

Thomas M. Walker
George R. Cobb
Mark D. Hansen
John S. Kinsey

VOLUME I

FINAL REPORT

Contract No. 68-02-3158, Technical Directive No. 8
MRI Project No. 4891-L(84)

February 16, 1983

For

Industrial Environmental Research Laboratory
Environmental Protection Agency
Cincinnati, Ohio 45268

Attn: Mark Stutsman

and is deposited in a hopper located beneath the collector. The collected dust is returned to the drum from the hopper using a positive flow pneumatic system.

2.2 PROCESS OPERATION

As an integral part of the field sampling program, data on the operation of the plant were obtained which characterized the various parameters affecting the generation of emissions. Such data included the plant production rate, the raw material throughput, the asphalt content of the mix, the ratio of recycle material to total aggregate, and the temperature of the hot mix and the effluent gas from the drum mixer. This information was collected in the form of hard copy printouts from the computerized system controlling plant operation. The printouts were obtained approximately every 30 min throughout each sampling period. A summary of the process operating data collected during the program is presented in Table 2.2, and photocopies of the original printouts are provided in Appendix B.

During the period when testing was being conducted at the Bowen plant, a number of different types of asphalt paving were produced depending on individual customer requirements. Each type of mix is designated according to its job mix number, as shown in Table 2.2. The job mix number specifies the type and quantity of aggregate and asphalt cement required to produce a particular grade of asphalt paving. In the process, the proper amount of material from each of the cold feed bins (including the recycle feed bin) is provided to supply aggregate of the appropriate gradation. Hot asphalt cement is also metered to the process according to the job mix specifications. Allowances have been made in the job mix formula to account for the asphalt content of the old asphalt concrete when recycled material is used.

Table 2.3 provides a summary of the job mix specifications available for each type of paving produced by the Bowen plant as a function of the aggregate gradation and asphalt content.

TABLE 2.2. SUMMARY OF PROCESS OPERATING DATA AT BOWEN CONSTRUCTION COMPANY

Date	Time (h)	Raw material throughput (tons/h)[d] Total aggregate[a]	Asphalt cement	Production rate (tons/h)[d]	Asphalt content of mix (wt. %)	Job mix No.	Recycle material/total aggregate (%)	Hot mix exit temp. (°F)	Dryer gas exit temp. (°F)[b]
10/7/81	13:30	362	10.3	372	4.56	8	28.2	320	338
	14:00	316	11.1	327	4.64	8	30.4	293	330
	14:32	314	11.2	325	4.64	8	29.0	292	334
	15:00	322	10.9	333	4.61	8	30.7	305	342
10/8/81[c]	-	-	-	290	-	8	-	-	345
10/9/81	08:50	309	10.9	320	4.83	8	30.4	304	359
	09:15	309	10.8	320	4.75	8	29.4	307	356
	10:00	321	8.8	330	3.58	9	29.9	287	363
	10:30	316	8.8	325	3.94	8	29.4	308	361
	11:00	304	9.1	313	-	8	29.3	305	359
	11:30	312	8.8	321	3.93	8	30.8	307	362
	12:00	306	9.1	315	4.10	9	30.4	301	356
	12:30	300	8.0	308	3.78	9	28.3	306	359
	13:00	322	10.4	332	3.77	8	29.8	296	354
	13:30	274	11.4	285	5.05	8	36.1	298	340
	14:00	249	9.2	258	5.40	8	30.5	297	363
	14:30	245	8.8	254	5.01	8	29.5	291	351
	15:00	235	8.8	244	4.97	8	28.1	311	356
	15:30	-	7.2	-	3.77	9	-	288	337
10/16/81	10:30	257	13.7	271	5.05	5	0	301	335
	11:05	262	8.9	271	4.49	8	30.9	299	379
10/19/81	08:00	265	8.7	274	4.41	8	31.3	293	359
	08:30	-	-	-	-	8	-	-	-
	09:00	274	8.7	283	4.37	8	32.1	298	358
	09:30	275	8.6	284	4.49	8	32.7	297	363
	10:00	253	8.4	261	4.53	8	31.2	298	362
	10:30	245	8.6	254	4.57	8	27.8	260	379
	11:00	256	8.6	265	4.33	8	30.9	318	364
	12:00	213	9.4	222	4.20	5	0	318	348
	12:30	253	8.3	261	4.65	8	31.2	305	342
	13:00	260	8.2	268	4.53	8	31.5	307	352
	13:30	171	8.8	180	4.54	5	2.3	299	357
	14:00	228	7.6	236	5.17	8	35.1	302	361
	14:30	218	11.7	230	4.95	5	0	311	341
10/20/81	08:00	223	7.9	231	4.53	8	30.0	312	361
	08:30	222	7.7	230	4.61	8	29.7	317	368
	09:00	216	11.4	227	4.95	5	0	307	346
	10:00	212	7.1	219	4.45	8	31.1	307	344
	10:30	214	6.6	221	4.66	5	29.0	316	358
	11:00	263	8.6	272	4.57	8	31.6	306	349
	11:30	278	9.5	288	4.61	8	30.2	316	365
	12:00	298	10.2	308	4.53	8	30.5	295	352
	12:30	304	10.0	314	4.61	8	31.6	293	351
	13:00	245	8.1	253	4.57	8	29.3	314	367
	13:25	211	8.7	220	4.53	8	17.5	307	351
10/21/81	08:30	230	7.9	238	4.61	8	29.1	296	343
	09:15	245	12.5	258	4.97	6	0	297	321
	09:45	239	12.4	251	4.89	6	0	296	331
	10:15	190	9.5	200	4.73	6	0	302	345
	11:15	195	9.8	205	4.81	6	0	313	343
	12:00	185	10.3	195	4.98	4	0	314	338
	12:30	185	10.1	195	5.14	4	0	314	335

(continued)

TABLE 2.2. (concluded)

Date	Time (h)	Raw material throughput (tons/h)[d] Total aggregate[a]	Asphalt cement	Production rate (tons/h)[d]	Asphalt content of mix (wt. %)	Job mix No.	Recycle material/total aggregate (%)	Hot mix exit temp. (°F)	Dryer gas exit temp. (°F)[b]
10/22/81	07:45	146	7.9	154	5.18	4	0	325	340
	08:30	161	9.0	170	5.14	4	0	326	345
	09:00	160	8.8	169	5.14	4	0	318	334
	09:30	147	8.1	155	5.14	4	0	333	345
	10:00	160	8.8	169	5.14	4	0	331	348
	10:30	163	8.8	172	5.10	4	0	325	338
	11:00	189	10.3	199	4.94	4	0	315	333
	11:30	180	9.9	190	5.14	4	0	324	357
	12:30	190	10.3	200	5.10	4	0	320	329
	13:30	194	10.4	204	5.10	4	0	325	333
10/26/81	09:30	157	8.1	165	5.03	5	0	327	353
	10:00	152	7.9	160	5.03	5	0	318	336
	10:30	154	8.1	162	4.95	5	0	315	348
	11:00	163	8.4	171	4.99	5	0	317	336
	11:30	156	8.0	164	4.99	5	0	322	343
	12:00	191	10.0	201	5.07	5	0	309	330
	12:30	180	9.8	190	5.03	5	0	334	352
	13:00	212	11.0	223	4.99	5	0	324	353
	13:30	215	11.7	227	4.99	5	0	332	363
	14:00	234	12.2	246	4.99	5	0	307	337
	14:30	238	12.9	251	5.03	5	0	325	357
	15:00	192	12.4	204	5.19	5	0	329	374
10/27/81	08:00	206	10.9	217	4.99	5	0	339	375
	08:30	207	11.1	218	5.03	5	0	340	362
	09:00	199	11.0	210	4.99	5	0	335	366
	09:30	209	10.8	220	4.95	5	0	329	363
	10:30	185	9.6	195	5.19	5	0	341	371
	11:00	203	10.7	214	4.83	5	0	332	338
	14:00	134	7.0	141	4.95	5	0	327	339
	14:30	131	6.9	138	4.93	5	0	344	346
10/30/81	08:00	193	10.0	203	5.01	5	0	337	341
	08:30	186	9.9	196	4.98	5	0	330	348
	09:00	189	9.8	199	5.01	5	0	316	351
	10:00	188	9.9	198	4.98	5	0	333	348
	10:30	186	9.9	196	4.93	5	0	323	335
	11:00	186	10.0	196	4.85	5	0	315	361
	11:30	188	9.9	198	4.85	5	0	333	359
	12:00	167	8.7	176	4.85	5	0	342	331
	12:30	163	8.7	172	5.01	5	0	330	347
	13:00	160	8.7	169	4.98	5	0	328	333
	13:30	143	7.8	151	5.06	5	0	332	342
11/6/81	10:00	264	8.4	272	4.21	10	29.9	308	367
	10:30	268	8.8	277	4.45	10	30.2	303	372
	11:00	265	8.8	274	4.45	10	29.8	309	378
	11:30	261	8.7	270	4.42	10	29.9	310	360
	12:00	248	8.0	256	4.45	10	30.6	312	354

[a] Total aggregate = virgin material + recycled asphalt pavement.

[b] Measured at inlet to baghouse.

[c] All process data for this date are daily averages reconstructed from plant historical records.

[d] Short tons/hour; 1 short ton = 2,000 lb.

TABLE 2.3. JOB MIX SPECIFICATIONS

Job mix No.	Aggregate gradation: Coarse aggregate (% > 8 mesh)[a]	Aggregate gradation: Fine aggregate (% < 8 mesh)[a]	Aggregate gradation: Mineral filler (% < 200 mesh)[a]	Asphalt content of mix (% weight)[b]
4	36.5	63.5	3.6	5.2
5	47.8	52.2	3.4	5.0
6	47.8	52.2	4.0	4.9
8[c]	45.8	54.2	5.9	4.9
9	Not Available			
10[c]	54.6	45.4	5.7	5.1

[a] Percent of total aggregate.

[b] Percent of total mix.

[c] Includes recycled asphalt paving.

It should be noted that the mineral filler content shown in Table 2.4 is that percent of the total aggregate (or recycle) below 200 mesh which is indigenous to the material itself and should not be misinterpreted as supplementary mineral filler added to the aggregate.

In addition to collecting process data, samples of both the virgin aggregate and the recycled asphalt concrete being used as raw material were collected. These samples were taken from the appropriate belt conveyor just prior to being transferred into the drum mixer. The samples were stored in polyethylene bottles in the field for transport back to the laboratory for analysis. These samples were then analyzed gravimetrically for surface moisture. The virgin material dried in a laboratory oven at 110°C for 24 h; and the recycle material at 110°C for 1.5 h. The raw data sheets of the moisture analyses are contained in Appendix C. The aggregate and recycle samples were then graded according to size by dry sieving using standard AASHTO test methods. Since MRI's nest of sieves does not contain a No. 8 screen, which is the cutoff between coarse and fine aggregate, the percent in each of these ranges was obtained through a linear regression analysis of the entire aggregate size distribution. Again, it should be noted that the mineral filler content is that which is indigenous to the material itself and not added to the mix. The results of the raw material analyses are provided in Table 2.4. The raw data of the dry sieve and moisture analyses are provided in Appendix D. Also contained in this appendix are the graphs plotted to determine the cut point between coarse and fine aggregate.

Included in the data collected during the sampling program was an analysis of the asphalt cement used by Bowen in their process. This cement was a standard 60-70 paving asphalt manufactured by the Amoco Oil Company at their refinery in Sugar Creek, Missouri. An analysis of the asphalt cement is contained in Table 2.5. This information was supplied by Amoco Oil Company.

TABLE 2.4. SUMMARY OF RAW MATERIAL ANALYSES

Date collected	Time (h)	Type of raw material: Virgin aggregate	Type of raw material: Recycled paving	Coarse fraction[a] (% > 8 mesh)	Fine fraction[a] (% < 8 mesh)	Mineral filler[a] (% < 200 mesh)	Surface moisture (wt. %)
10/7/81	SoRI Run #1	X		44.3	55.7	5.4	2.1
			X	72.7	27.3	0.1	0.9
10/9/81	SoRI Run #3	X		77.6	22.4	1.4	1.4
			X	87.3	12.7	0.1	0.9
	15:30	X		69.0	31.0	2.2	1.3
			X	61.1	38.9	0.8	0.8
10/19/81	13:30	X		61.5	38.5	4.2	2.5
			X	74.7	25.3	0.2	1.5
10/20/81	08:15	X		65.2	34.8	2.7	2.5
			X	75.2	24.8	0.2	1.7
	13:30	X		57.7	42.3	3.5	2.4
			X	79.1	20.9	0.7	1.5
10/21/81	09:00	X		49.5	50.5	3.1	2.5
10/22/81	08:30	X		24.4	75.6	2.3	4.0
	12:00	X		28.3	71.7	2.9	5.4
10/26/81	11:00	X		41.0	59.0	4.5	4.9
	13:15	X		49.1	50.9	3.9	3.1
10/27/81	08:40	X		53.3	46.7	2.5	3.1
	14:20	X		57.3	42.7	2.2	3.1
10/30/81	08:50	X		59.8	40.2	1.5	2.3
11/6/81	10:15	X		72.1	27.9	4.1	2.0
			X	66.8	33.2	0.7	3.2

[a] Percent of total material.

TABLE 2.5. ANALYSIS OF ASPHALT CEMENT

Parameter	Specification	Test results
Penetration (at 77°F)	0.6-0.7 mm	0.62 mm
Flash point	450°F	615°F
Ductility (at 77°F)	100 cm	150+ cm
Solubility	99%	99.96%
Specific gravity	-	1.035

Source: Amoco Oil Company.

3.3 SAMPLING PROCEDURES

The preliminary inlet and outlet test data taken prior to performing the actual emission tests at the asphalt plant are contained in Appendix F. The preliminary inlet data contain an attempted Method 17 run using 48 sampling points (traversing 24 points per port). However, only two points were sampled because of the high loading. The testing strategy decided upon is discussed in more detail in Section 3.3.2. Also contained in Appendix F are the dry molecular weight determinations used in the final calculations. The dry molecular weight of the stack gas was determined daily at the inlet and outlet of the baghouse.

3.3.1 Pretest Preparations

3.3.1.1 Particulate Mass--

3.3.1.1.1 EPA Method 5 train--Four-inch diameter Type A/E (Gelman Sciences, Inc.) glass fiber filters were used for particulate collection substrates in the EPA Method 5 train used at the baghouse inlet. The filters were placed in numbered 4-3/4 in. diameter by 3/16 in. deep aluminum weighing pans. The filters and weighing pans were then placed in a constant humidity and temperature room for 24 h, after which each filter and its corresponding numbered weighing pan were weighed on a Mettler Model AK 160 electronic balance to the nearest 0.1 mg. The filters and weighing pans were again equilibrated for 6 h and weighed. This procedure was repeated until two consecutive weighings agreed within 1.0 mg. The Method 5 filter tare weights are found in Appendix G. After completion of weighings, the filters were placed in plastic petri dishes for transport to the test site.

Two-hundred and fifty milliliter capacity glass beakers were used for recovery of mass train samples. The beakers were first washed in Alconox detergent and the rinsed with tap water. After the beakers were numbered with a lead pencil on the etched surface of the beaker, they were rinsed with distilled water. The beakers were then heated in an oven to 500°F for 1 h to burn off any organic material present. The beakers were transferred using beaker tongs to an equilibration room and equilibrated for 24 h. The beakers were then weighed on a Mettler Model AK 160 electronic balance to the nearest 0.1 mg. The beakers were equilibrated for 6 h and then re-weighed. This procedure was repeated until two consecutive weighings agreed within 1.0 mg. Tare weights for 250 ml beakers are presented in Appendix G. After completion of weighing, the beakers were placed in sterile plastic Whirl-Pak containers and put into their original box for shipping.

3.3.1.1.2 EPA Method 17 train--Gelman type A/E 47-mm diameter glass fiber filters were used for particulate collection substrates in the EPA Method 17 train used at the baghouse outlet location. The filters were placed in numbered 57-mm diameter aluminum weighing pans. The equilibration and weighing procedures used on these filters were identical to the procedures used for the EPA Method 5 filters. Method 17 filter tare weights are presented in Appendix G. Plastic petri dishes were used as shipping containers.

One-hundred and fifty milliliter capacity glass beakers were used for recovery of EPA Method 17 samples. The beakers were cleaned, equilibrated, and weighed according to the procedures described above for the EPA Method 5 beakers. Tare weights for the 150-ml beakers are presented in Appendix G. These beakers were transported in sterile plastic Whirl-Pak containers.

3.3.1.2 Particle Size--

3.3.1.2.1 Andersen high capacity stack sampler with 15-μm preseparator--The entire Andersen HCSS impactor and 15-μm preseparator system and nozzles were washed in detergent and rinsed with tap water, distilled water, and acetone. The acceleration and vent tubes were cleaned with a high pressure air stream.

A 1-1/2 in. diameter by 4-3/4 in. long aluminum tube was used as a container for each glass fiber thimble filter. The aluminum tube also served as a weighing container. The thimble filter and aluminum tube were prepared for field use as follows:

- Aluminum tubes were numbered with an engraver.
- Aluminum tubes and lids were washed in Alconox detergent.
- Aluminum tubes and lids were first rinsed with tap water, then with deionized, distilled water.
- Aluminum tubes and lids were heated in an oven to 500°F for 1 h to remove any potential organic contaminants. After heating, the aluminum tubes were handled only with beaker tongs. The aluminum lids were handled with latex surgical gloves since they were not weighed.
- The aluminum tubes and lids were removed from the oven and allowed to cool.
- A thimble filter was placed in each container.
- The thimble filter and aluminum tube were placed in a constant humidity room for 24 h at ambient temperature and pressure.
- The aluminum tube and thimble filter were weighed to the nearest 0.1 mg on a Mettler Model AK 160 electronic balance. The aluminum tube lid was not desiccated or weighed.
- The aluminum tube and thimble filter were desiccated for 6 h.
- The aluminum tube and thimble filter were weighed a second time.

- Weighings were repeated until two consecutive weighings agreed within 1.0 mg.

- The lid was placed on the aluminum tube.

- Aluminum tubes were wrapped in aluminum foil and placed in plastic Whirl-Paks for shipment.

Aluminum weighing pans 57 mm in diameter and 20 mm deep were used in recovering samples from the first four impactor stages. Each weighing pan was numbered with a metal engraver. The aluminum weighing pans were then desiccated and weighed according to the procedures used for the aluminum tubes and thimble filters. The aluminum weighing pans were placed in 100 mm diameter by 20 mm deep plastic petri dishes used as shipping containers. Thimble filter and aluminum weighing pan tare weights can be found in Appendix G.

3.3.1.2.2 Andersen Mark III impactor with 15-μm preseparator--Ten 3-in. aluminum foil squares were cut to serve as holders for each filter set. The aluminum foil squares were folded in half, labeled, and the appropriate glass fiber filter substrate (Andersen 2000) placed inside. The equilibration and weighing procedures used were as follows:

- The filter sets were equilibrated in a constant humidity room for 24 h.

- The filter and its aluminum foil holder were weighed on a Cahn Instruments Model 27 electrobalance to the nearest 0.01 mg.

- The filter sets were equilibrated for another 6 h.

- The filters were weighed a second time.

- The equilibration and weighing procedures were repeated until two consecutive weighings agreed within 0.05 mg.

- Each complete filter set was placed in a glassine envelope for shipping.

Andersen Mark III impactor substrate tare weights are found in Appendix G.

3.3.2 Testing Strategy

The Southern Research Institute "Procedure Manual for Inhalable Particulate Sampler Operation," November 30, 1979, prepared for EPA (SoRI-EAS-79-761, 4181-37), was used to determine most of the sampling criteria for both the particle sizing and mass tests. Four individual sampling points were used rather than a standard traverse of the duct, except for the inlet. Also, the criterion for isokinetic sampling was expanded to ± 20% rather than the standard ± 10%.

3.3.2.1 Baghouse Inlet--

According to the procedures manual cited above, the recommended sampling points for circular and square or rectangular ducts can be determined using Figure 3.7. However, due to the duct configuration and the extremely high loading at the inlet, it was decided to deviate from the recommended sampling points for the total mass tests. Instead of sampling at one point during a run, it was decided to traverse six points. A traverse of the duct was necessary to obtain total mass data that would be unbiased by stratification. Six points were chosen because of the short sampling time dictated by the high loading of the inlet. The particle sizing tests were conducted using normal inhalable particulate testing procedures. (Refer to Figure 3.2.)

3.3.2.2 Baghouse Outlet--

The testing strategy used in testing the outlet employed normal inhalable particulate testing procedures for both particle sizing and total mass tests.

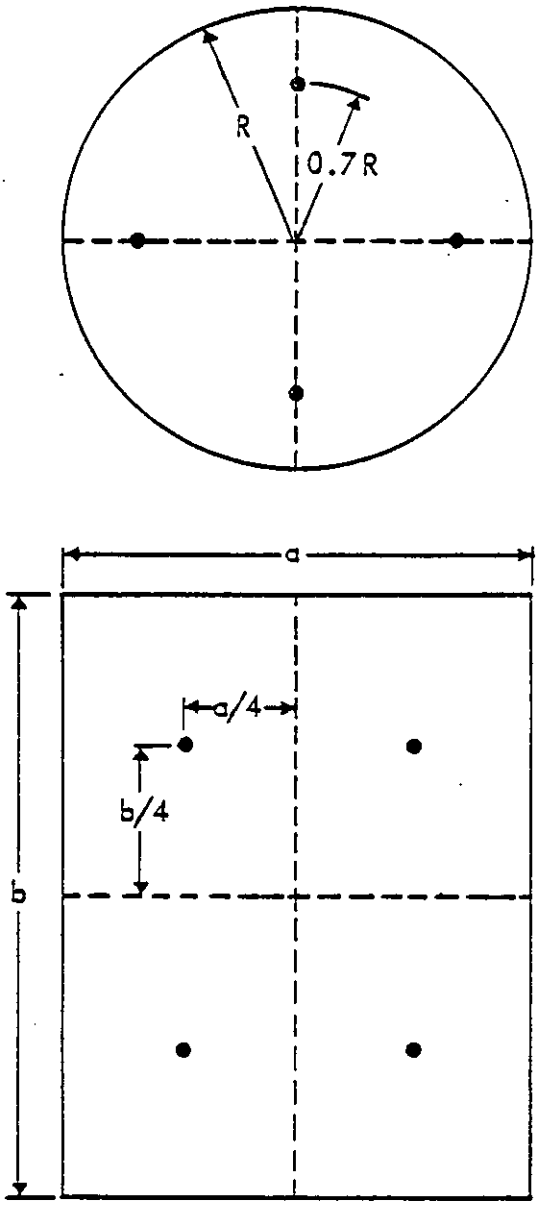


Figure 3.7. Recommended sampling points.

Source: Southern Research Institute, "Procedure Manual for Inhalable Particulate Sampler Operation," prepared for EPA, November 30, 1979. (SoRI-EAS-79-761, 4181-37).

SECTION 4.0

SUMMARY OF RESULTS

Results of the testing program at the Bowen Construction Company asphalt plant are summarized in this section. The tabular and graphic presentations that follow were derived from reduction of the raw field data found in Appendix I and the laboratory and analytical data found in Appendix G. The raw data were combined and reduced by a computer program developed by MRI to produce the printouts found in Appendix J. The information contained in these computer printouts was used in the construction of the graphs and tables in this section.

Only data that have met specific acceptance criteria are summarized in this section. These criteria, as obtained from "Procedures Manual for Inhalable Particulate Sampler Operation," prepared by Southern Research Institute for EPA, are:

1. Each total mass and particle sizing run must be within ± 20% of isokinetic.

2. The particulate grain loading from the total mass train (EPA Method 5 or Method 17) and the corresponding particle size train (Andersen HCSS or Andersen Mark III with 15 μm preseparator) must be within ± 50%.

The data that has met this criteria is in Table 4.1. Two total mass and four particle sizing tests consisting of four runs per test (one run per quadrant on particle sizing) were conducted at the baghouse inlet test site. Two total mass and two particle sizing tests consisting of four runs each (one run per quadrant) were conducted at the baghouse outlet test site.

TABLE 4.1. SUMMARY OF BAGHOUSE INLET AND OUTLET ACCEPTANCE CRITERIA RESULTS

Test No.	Run No. source-run-quad	Test date	% Isokinetic	Particulate loading gr/dscf[a]	$\bar{x}$[b]	% from $\bar{x}$	Run No. Source-run	Test date	% Isokinetic	Particulate loading gr/dscf[a]	$\bar{x}$[b]	% from $\bar{x}$
	Inlet Particle Sizing Train						Inlet mass train					
1	1-1-1(B)	10/26/81	94.9	15.1	21.9	22	1-1(c)	10/21/81	102.0	28.9	27.6	25
	1-1-2	10/21/81	93.2	21.2								
	1-1-3	10/22/81	95.1	17.5			1-2	10/22/81	99.8	26.3		
	1-1-4	10/21/81	101.6	33.6								
2	1-2-1(C)	11/06/81	89.7	6.6	16.0	11	1-3	10/20/81	100.9	19.3	16.0	27
	1-2-2(B)	10/22/81	96.0	18.6								
	1-2-3	10/26/81	99.1	12.7			1-4	10/20/81	98.8	12.8		
	1-2-4	10/22/81	113.2	26.1								
3	1-3-1	10/27/81	90.9	16.9	19.7	9	1-5	10/22/81	106.1	24.7	22.4	2
	1-3-2	10/26/81	95.4	18.9								
	1-3-3	10/27/81	89.9	10.4			1-6(B)	10/27/81	106.0	20.1		
	1-3-4	10/26/81	98.8	32.5								
4	1-4-1	10/30/81	110.1	7.6	14.3	20	1-7	10/26/81	104.7	24.8	22.1	0.3
	1-4-2	10/27/81	111.2	10.1								
	1-4-3	10/30/81	93.6	17.5			1-8	10/27/81	104.2	18.8		
	1-4-4	10/30/81	109.5	22.1								
					$\bar{x}$ = 18.0						$\bar{x}$ = 22.0	
	Outlet Particle Sizing Train						Outlet mass train					
1	0-1-1(B)	10/21/81	120.1	0.0298	0.0316	5	0-1-1	10/22/81	95.6	0.0578	0.0537	0
	0-1-2	10/19/81	117.7	0.0310			0-1-2	10/20/81	97.2	0.0505		
	0-1-3	10/20/81	104.4	0.0188			0-1-3(B)	10/19/81	103.0	0.0639		
	0-1-4	10/22/81	114.3	0.0467			0-1-4	10/20/81	104.0	0.0426		
2	0-2-1	10/30/81	105.8	0.0232	0.0352	5	0-2-1	10/26/81	95.7	0.0539	0.0538	0
	0-2-2	10/22/81	101.2	0.0348			0-2-2(B)	10/27/81	100.7	0.0293		
	0-2-3	10/27/81	100.8	0.0409			0-2-3	10/22/81	102.5	0.0861		
	0-2-4	10/26/81	92.5	0.0419			0-2-4(C)	10/30/81	96.2	0.0458		
					$\bar{x}$ = 0.03338						$\bar{x}$ = 0.0538	

[a] Grains per dry standard cubic foot.

[b] Mean.

To further scrutinize the particle sizing data an average grain loading was determined for the 16 inlet runs and the 8 outlet runs. This average was compared to the average grain loading of each test. If the average varied by more than 50%, runs within that test would be compared to the grain loading found in the corresponding mass run. If these values disagreed by less than 50%, the deviation probably indicated a high degree of stratification and all data were retained.

4.1 INHALABLE PARTICULATE (IP) EMISSION FACTORS

The IP emission factors for a typical source were calculated for 15.0, 10.0, and 2.5 μm particles as follows:

A total mass emission factor, indicating the amount of particulate matter released into the atmosphere per unit of asphalt concrete produced, in pounds per ton was calculated for each run of each mass test. The total mass emission factor (lb/ton) was derived by dividing the total mass emission rate (lb/hr) calculated from the mass train data, by the production rate (tons/hr). Production data for the plant was provided by the Bowen Construction Company as described in Section 1. The calculation for a single run was based on the assumption that the average stack velocity during the run was the same as the velocity measured at the sampling point of the quadrant being sampled. In addition, the individual emission factors for each run were calculated based on the plant production rate during the period when the samples were collected with no adjustment being made for other variations in process operating conditions. The IP emission factors were calculated using the total mass emission factor derived from the Method 5 and Method 17 data rather than a factor which could have been calculated from the total mass collected by the particle sizing device.

The total mass collected during a run in the particle sizing device, and the mass collected on each individual stage was entered into a computer program along with the criteria to determine the actual D_{50} of each stage.

The D_{50} of a stage is the particle diameter at which the stage achieves 50% efficiency; one half of the particles of that diameter are captured and one half are not. The computer printouts of the particle sizing tests in Appendix J indicate cumulative percent greater than the stated D_{50}, whereas the graphs and tables indicate D_{50} as cumulative percent less than stated size. The cumulative percent less than stated size vs. the stated size (D_{50}) were then plotted for each of the four runs that constitute a test. Note: The cumulative percent less than stated size is determined by subtracting the numbers found in the row labeled "cum.% with filter" from 100.

To determine exactly what percentage of the total mass was less than 2.5, 10, and 15 microns, the cumulative percent greater than stated size and D_{50} from the abovementioned computer printouts were entered into a spline equation. A program for handling impactor data using a spline fit has been developed by J. E. Johnson et al. ("A Computer Based Cascade Impactor Data Reduction System," EPA-600/7-78-042, March 1978). An improvement to this program has recently been completed by MRI and was used in this study to determine emission factors. IP emission factors were calculated by multiplying the percentage of the total mass derived by the spline equation for the desired D_{50} by the total mass emission factor (lb/ton). The particle diameter upper limit was set at 50.0 μmA for the calculations using the spline fit.

4.2 CALCULATION PROCEDURES FOR THE INLET AND OUTLET OF THE BAGHOUSE

Due to the extremely high loading at the inlet, a deviation from normal IP protocol was used to calculate these emissions. The outlet emissions were calculated using the normal IP methods discussed earlier. The total mass runs were matched with the particle size runs as shown in Table 4.2 and 4.3.

All total mass samples taken at the inlet were collected using a six point traverse instead of being collected from one point at the center of a quadrant. Because of this, the mass and particle sizing runs could not be matched quadrant by quadrant. Total mass runs were matched with particle sizing runs according to time and day (see Appendix A). The last 2 days of

TABLE 4.2. BAGHOUSE OUTLET TOTAL MASS AND PARTICLE SIZING COORDINATION

Particle sizing run	Total mass run
0-1-1(B)	0-1-1
0-1-2 (recycle)	0-1-2 (recycle)
0-1-3 (recycle)	0-1-3(B) (recycle)
0-1-4	0-1-4 (recycle)
0-2-1 (recycle)	0-2-1
0-2-2	0-2-2(B)
0-2-3	0-2-3
0-2-4	0-2-4(C)

TABLE 4.3. BAGHOUSE INLET TOTAL MASS AND PARTICLE SIZING COORDINATION

Particle sizing run	Total mass run
None	I-3 (recycle)
None	I-4 (recycle)
I-1-4 I-1-2	I-1(C)
I-1-3 I-2-2(B)	I-2
I-2-4	I-5
I-2-3 I-3-2 I-1-1(B) I-3-4	I-7
I-3-1 I-3-3	I-8
I-4-2	I-6(B)
I-4-1 I-4-3 I-4-4 I-2-1(C) (recycle)	None

testing no total mass runs were conducted. The average total mass emission factor (lb/ton), calculated from all eight of the inlet mass runs (Table 4.3) was applied to the particle sizing runs conducted on that day.

4.3 DATA PRESENTATION FORMAT

Summary tables for both the baghouse inlet and outlet test locations are presented as follows:

Tables 4.4 and 4.5 present impactor particle size run sampling data including mass (mg), D_{50} values, and the cumulative percent less than stated size for each stage of the impactor.

Tables 4.6 and 4.7 present the total mass emission factors (lb/ton) and the IP emission factors for 2.5-, 10.0-, and 15-μm particles. An average ratio of the grain loading determined from the particle sizing train to the grain loading determined from the mass train, is presented in Table 4.7. This ratio was not included in the data for the inlet (Table 4.6) due to the six-point traverse (instead of quadrant sampling) used to obtain the sample.

The computer results of the modified EPA Method 5 and Method 17 train field data containing the calculated grain loading and the emission rate in pounds per hour, are presented in Appendix J. IP emission factors for both the inlet and the outlet are summarized in Table 4.8.

The data results are also presented in graphic form for both the baghouse inlet and outlet test locations. These graphs are presented as follows:

Figures 4.1, 4.2, 4.3, 4.4, 4.5, and 4.6 present the results of each individual test, which consisted of four separate runs (one per quadrant). The data presented include particle size (D_{50}) versus cumulative percent less than stated size and emission factors for 2.5, 10.0, and 15.0 μm.

TABLE 4.4. PARTICLE SIZE RUN TEST SAMPLING DATA, BAGHOUSE INLET

Test No.	Run No. source-run-quad	15-μm Cyclone			Stage 1			Stage 2			Cyclone			Filter	
		Mass (mg)	D_{50} size (μm)	Cum. % less than stated size	Mass (mg)	D_{50} size (μm)	Cum. % less than stated size	Mass (mg)	D_{50} size (μm)	Cum. % less than stated size	Mass (mg)	D_{50} size (μm)	Cum. % less than stated size	Mass (mg)	D_{50} size (μm)
1	1-1-1(B)	4,775.2	14.8	30.2	95.2	11.4	28.8	617.5	6.3	19.7	1,091.0	1.9	3.8	258.0	< 1.9
	1-1-2	6,088.7	15.5	25.0	125.0	11.8	23.5	566.6	6.7	16.5	1,143.3	1.9	2.4	198.0	< 1.9
	1-1-3	6,345.5	15.1	19.2	68.5	11.5	18.3	399.4	6.5	13.3	906.8	1.9	1.7	134.3	< 1.9
	1-1-4	10,607.6	15.2	17.6	179.5	11.6	16.2	750.9	6.5	10.4	977.9	1.9	2.8	356.5	< 1.9
2	1-2-1(C)	212.91	14.5	26.7	45.6	11.2	25.1	221.8	6.2	17.5	446.3	1.8	2.1	60.8	< 1.8
	1-2-2(B)	5,881.3	15.6	25.7	127.0	11.7	24.1	621.1	6.6	16.2	1,061.0	2.0	2.8	222.6	< 2.0
	1-2-3	4,157.7	15.4	22.9	60.4	11.7	21.7	362.7	6.6	15.0	746.8	1.9	1.2	62.4	< 1.9
	1-2-4	9,068.9	15.0	22.9	406.6	11.5	19.5	767.3	6.4	12.9	1,038.8	1.9	4.1	481.7	< 1.9
3	1-3-1	5,718.0	15.7	22.3	364.8	11.7	17.4	200.5	6.6	14.7	975.1	2.0	1.4	104.1	< 2.0
	1-3-2	6,113.0	15.5	23.5	81.0	11.7	22.5	505.7	6.6	16.2	997.5	2.0	3.7	294.8	< 2.0
	1-3-3	3,086.1	15.4	33.5	62.2	11.6	32.1	393.8	6.5	23.6	937.4	1.9	3.4	159.4	< 1.9
	1-3-4	10,346.7	15.2	19.8	170.5	11.6	18.5	888.7	6.5	11.6	1,062.2	1.9	3.4	435.3	< 1.9
4	1-4-1	2,149.4	15.5	35.8	48.4	11.7	34.4	301.8	6.61	25.4	671.9	2.0	5.3	177.1	< 2.0
	1-4-2	3,242.0	15.4	27.8	78.4	11.7	26.00	348.8	6.6	18.2	642.8	1.9	3.9	175.2	< 1.9
	1-4-3	7,794.4	15.4	20.2	89.3	11.6	19.3	550.6	6.6	13.6	874.2	1.9	4.7	456.6	< 1.9
	1-4-4	9,585.9	15.5	21.4	178.5	11.7	20.0	873.4	6.6	12.8	785.0	2.0	6.4	777.3	< 2.0

(Data Reproduced in Table 3-12)

TABLE 4.5. PARTICLE SIZE TEST SAMPLING DATA, BAGHOUSE OUTLET

Test No.	Run No. source-run-quad	15-μm Cyclone Mass (mg)	15-μm Cyclone D_{50} size (μm)	15-μm Cyclone Cum. % less than stated size	Stage 0 Mass (mg)	Stage 0 D_{50} size (μm)	Stage 0 Cum. % less than stated size	Stage 1 Mass (mg)	Stage 1 D_{50} size (μm)	Stage 1 Cum. % less than stated size	Stage 2 Mass (mg)	Stage 2 D_{50} size (μg)	Stage 2 Cum. % less than stated size	Stage 3 Mass (mg)	Stage 3 D_{50} size (μg)	Stage 3 Cum. % less than stated size
1	0-1-1(B)	37.96	14.9	42.1	0.41	14.7	41.5	1.34	9.1	39.5	3.65	6.2	33.9	5.30	4.2	25.8
	0-1-2	84.91	14.7	21.0	0.51	14.4	20.5	0.89	9.0	19.7	3.94	6.1	16.0	4.44	4.1	11.9
	0-1-3	39.29	14.9	26.0	0.00	14.6	26.0	0.63	9.1	24.8	1.95	6.1	21.1	2.82	4.2	15.8
	0-1-4	72.37	14.8	31.6	0.61	14.7	31.1	0.73	9.2	30.4	2.36	6.2	28.1	16.29	4.2	12.7
2	0-2-1	21.93	15.2	56.7	1.60	14.9	53.1	1.88	9.3	49.8	4.33	6.3	41.2	4.56	4.3	32.2
	0-2-2	49.78	15.0	35.7	0.67	14.7	34.9	0.85	9.2	33.8	3.36	6.2	29.4	4.33	4.2	23.8
	0-2-3	61.54	14.6	32.8	3.52	14.3	28.9	1.98	8.9	26.8	4.77	6.0	21.6	4.58	4.1	16.6
	0-2-4	71.68	15.4	37.0	7.79	15.0	30.1	3.38	9.4	27.2	5.75	6.3	22.1	6.57	4.3	16.3

Test No.	Run No. source-run-quad	Stage 4 Mass (mg)	Stage 4 D_{50} size (μm)	Stage 4 Cum. % less than stated size	Stage 5 Mass (mg)	Stage 5 D_{50} size (μm)	Stage 5 Cum. % less than stated size	Stage 6 Mass (mg)	Stage 6 D_{50} size (μm)	Stage 6 Cum. % less than stated size	Stage 7 Mass (mg)	Stage 7 D_{50} size (μg)	Stage 7 Cum. % less than stated size	Filter Mass (mg)	Filter D_{50} size (μg)
1	0-1-1(B)	8.45	2.7	12.9	5.71	1.3	4.2	2.07	0.80	1.1	0.33	0.59	0.56	0.37	< 0.59
	0-1-2	5.43	2.6	6.8	4.74	1.3	2.4	1.71	0.78	0.82	0.57	0.58	0.29	0.31	< 0.58
	0-1-3	2.97	2.7	10.2	3.26	1.3	4.1	1.81	0.79	0.64	0.21	0.58	0.24	0.13	< 0.58
	0-1-4	0.00	2.7	12.7	12.4	1.3	1.0	0.00	0.81	1.0	0.88	0.59	0.20	0.21	< 0.59
2	0-2-1	5.68	2.7	21.0	5.09	1.3	11.0	2.60	0.81	5.8	1.54	0.60	2.8	1.40	< 0.60
	0-2-2	7.91	2.7	13.6	6.63	1.3	5.1	2.95	0.80	1.3	0.77	0.59	0.26	0.20	< 0.59
	0-2-3	7.04	2.6	8.9	5.09	1.3	3.3	2.45	0.78	0.64	0.46	0.57	0.14	0.13	< 0.57
	0-2-4	8.35	2.8	9.0	6.07	1.4	3.7	2.52	0.82	1.4	0.91	0.61	0.63	0.72	< 0.61

(Data Reproduced in Table 3-13)

TABLE 4.6. BAGHOUSE INLET EMISSION FACTORS BASED ON TOTAL MASS AND IMPACTOR SIZE DISTRIBUTION

Test No.	Run No. source-run-quad	Matching mass run	Total mass emission rate lb/h	Production rate[b] ton/h	Total mass emission factor lb/ton	IP emission factors < 2.5 μm (lb/ton)	< 10 μm (lb/ton)	< 15 μm (lb/ton)
1	1-1-1(B)	1-7	7,480	225	33.3	2.1	9.1	10.2
	1-1-2	1-1(C)	8,190	217	37.7	1.6	8.3	9.4
	1-1-3	1-2	6,930	162	42.8	1.4	7.5	8.3
	1-1-4	1-1(C)	8,190	217	37.7	1.5	5.6	6.7
					Avg. 37.9	Avg. 1.65	Avg. 7.6	Avg. 8.7
2	1-2-1(B)[a]	None	-	-	(30.9)	1.3	7.4	8.5
	1-2-2(B)	1-2	6,930	162	42.8	1.9	9.5	10.9
	1-2-3	1-7	7,480	225	33.3	0.8	6.8	7.6
	1-2-4	1-5	7,180	195	36.8	2.0	6.6	8.5
					Avg. 40.0	Avg. 1.5	Avg. 7.6	Avg. 8.9
3	1-3-1	1-8	5,840	215	27.2	0.75	4.5	5.8
	1-3-2	1-7	7,480	225	33.3	1.8	7.1	7.8
	1-3-3	1-8	5,840	215	27.2	1.6	8.3	9.1
	1-3-4	1-7	7,480	225	33.3	1.5	5.7	6.6
					Avg. 30.3	Avg. 1.4	Avg. 6.4	Avg. 7.3
4	1-4-1[a]	None	-	-	(30.9)	2.5	10.0	11.0
	1-4-2	1-6(B)	5,720	205	27.9	1.6	6.8	7.7
	1-4-3[a]	None	-	-	(30.9)	1.9	5.6	6.3
	1-4-4[a]	None	-	-	(30.9)	2.2	5.6	6.6
					Avg. 30.2	Avg. 2.1	Avg. 7.0	Avg. 7.9
		Non-matching mass runs						
		1-3	5,620	223	25.2			
		1-4	3,850	237	16.3			
	Total average		6,350	210	(30.9)[c]	1.7	7.2	8.2

Note: A column labeled "Ratio of total mass conc. to particle sizing conc." is not included on this table due due to the traversing of the mass runs rather than quadrant sampling.

[a] No paired mass run for this particle sizing run. Used the average total mass emission factor of all eight mass runs (30.9 lb/ton) to calculate IP emission factors.

[b] Average plant production rate during mass test run.

[c] This average was derived from the eight mass runs in Table 4.3.

(Data Reproduced in Table 3-27)

TABLE 4.7. BAGHOUSE OUTLET EMISSION FACTORS BASED ON TOTAL MASS AND IMPACTOR SIZE DISTRIBUTION

Test No.	Run No. source-run-quad	Total mass emission rate (lb/h)	Production rate (ton/h)	Total mass emission factor (lb/ton)[a]	Ratio of particle size train to total mass train conc.	IP emission factors		
						< 2.5 μm (lb/ton)	< 10 μm (lb/ton)	< 15 μm (lb/ton)
1	0-1-1(B)	11.5	164	0.07		0.008	0.028	0.03
	0-1-2	12.7	226	0.056		0.004	0.011	0.012
	0-1-3	16.6	216	0.077		0.007	0.019	0.021
	0-1-4	9.6	237	0.041		0.004	0.013	0.013
	Average	12.6	211	0.061	0.59	0.006	0.018	0.019
2	0-2-1	9.6	174	0.055		0.011	0.028	0.031
	0-2-2	7.3	216	0.034		0.004	0.012	0.012
	0-2-3	24.7	195	0.127		0.011	0.035	0.044
	0-2-4	10.0	178	0.056		0.004	0.016	0.021
	Average	12.9	191	0.068	0.65	0.008	0.023	0.027
	Total average	12.8	201	0.065		0.007	0.021	0.023

[a] Average plant production rate during test run.

(Data Reproduced in Table 3-28)

The data for particle size (D_{50}) versus cumulative percent less than stated size data have been plotted for each of the four separate runs. The average of the results from the four runs have also been presented as a line. This line was generated from the results of the spline fit of the selected particle diameters (2.5, 10.0, and 15.0 μm).

The calculated emission factors for 2.5, 10.0, and 15.0 μm are presented both as an average of the four runs and as a range of values for the four runs. The average of the four runs is presented as a line, whereas the range of values is presented as a vertical line at the selected diameters.

Figures 4.7 and 4.8 present the average of the results of all tests conducted at each testing location. There were four particle sizing tests of four runs per test conducted at the inlet location and two particle sizing tests of four runs per test conducted at the outlet location.

The average particle size (D_{50}) versus cumulative percent less than stated size for all tests is presented graphically. The plot was constructed by averaging all test data generated by the spline fit for the selected diameters of 2.5, 10.0, and 15.0 μm. The ranges of the individual test averages are also presented at the selected diameters.

The average emission factor for all tests is also represented by a line. The line was constructed by averaging the average of individual test results at the selected diameters of 2.5, 10.0, and 15.0 μm. The ranges of the individual test averages are presented at the selected diameters.

SECTION 5.0

CONDENSABLES TESTING RESULTS

This section summarizes tests for condensable emissions conducted by Southern Research Institute (SoRI) at Bowen Construction Company. The tests were conducted during the week of October 5 to 10, 1981. The IP condensable testing was performed using the EPA Stack Dilution Sampling System (SDSS) according to IP protocol. Both the sampling equipment and the protocol used are described in this section, followed by a presentation of test data and a brief discussion of the test results.

5.1 DESCRIPTION OF INSTRUMENT AND TEST PROCEDURES

5.1.1 Design of Stack Dilution Sampling System (SDSS)

A diagram of the major components of the SDSS is shown in Figure 5.1. In operation, gases from the process stream are drawn through the IP Dual Cyclone Sampler in which particles with an aerodynamic diameter greater than 15 μm and those in the range 2.5 to 15 μm are removed in two stages. The stack gas containing the fine particle fraction (< 2.5 μm) and condensable vapors passes through the heated probe and flexible sample line and is introduced axially into the bottom of the cylindrical dilution chamber. At this point the stack gases are mixed with cool, dry dilution air to form a simulated plume which flows upward through the dilution chamber. A standard 20 x 25 cm hi-vol filter is installed at the discharge end of the chamber which collects the fine particulate including any new particulate formed by condensation. The diluted stream is exhausted by a 1-hp blower or optionally by a standard hi-vol blower. Stack gas flow rate is measured by an orifice

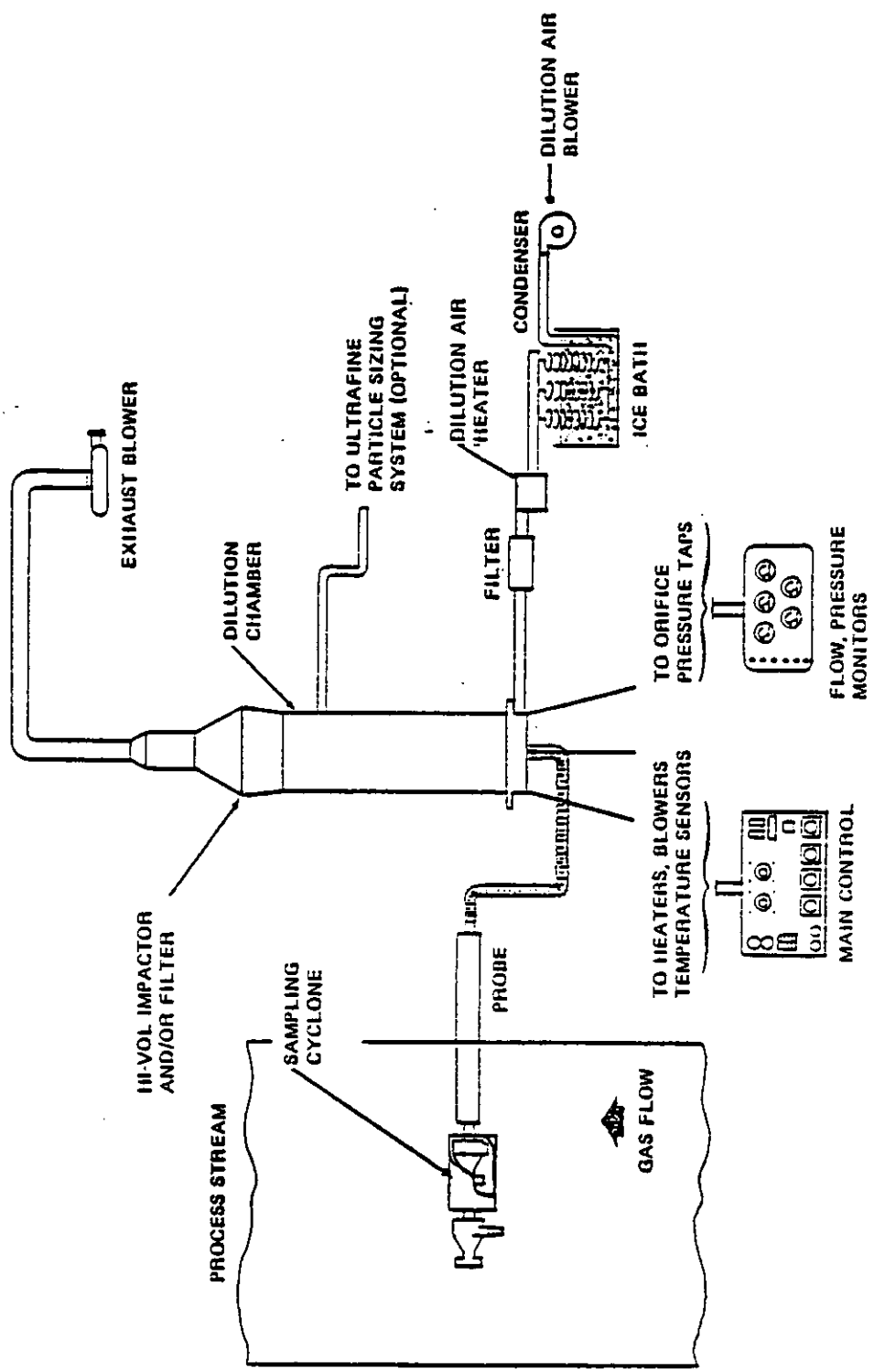


Figure 5.1. Diagram of stack dilution sampling system.

at the base of the dilution chamber. Dilution and exhaust flow are measured by orifices in the inlet and outlet lines, respectively.

Ambient dilution air is drawn through a blower and forced through an ice bath condenser. In this condenser the air is cooled to 5 to 8°C (41 to 46°F), depending on the flow and ambient temperature. More significantly, the dilution air humidity is reduced to about 0.57% by volume, corresponding to saturated air at the ice point. After the condenser, the air is reheated as required to reach 21.1°C (70°F) at the dilution chamber inlet, filtered through a HEPA-type absolute filter, and introduced into the dilution chamber. The dilution air enters a single tangential inlet at the base of the dilution chamber and passes through a set of flow straightening screens into the annular region surrounding the sample gas inlet. The ratio of the areas of the two inlets is such that for sample gas at room temperature the velocities of the sample and dilution streams are equal. Sample gas at stack temperature will be injected at a higher velocity proportional to the thermal expansion of the heated gas stream. This was judged the best simulation of a buoyant plume injected into stagnant air.

5.2 SPECIFICATIONS

The geometric and flow specifications were set by several constraints. The sample flow rate was set by the flow requirements of the IP cyclone sampler. Ideally, to approximate the conditions found in actual plumes, the dilution ratio should be high (approaching 10^3 to 10^4) and the mixing times long (tens of seconds). The actual dilution conditions represent a compromise dictated by limitations on the size of a portable field instrument. Geometric and flow specifications are given in Table 5.1.

Since the effect of varying dilution air temperature and humidity cannot be easily predicted for all typical process streams, standard conditions of 0.57% moisture by volume at 21.1°C (corresponding to about 24% relative humidity at 70°F) were chosen. This relatively dry dilution air should not be subject to water condensation for normal stack samples, yet is more realistic than totally dry air.

TABLE 5.1. SPECIFICATIONS FOR DILUTION SAMPLING SYSTEM

Geometric	
• Active length of dilution chamber:	48 in. (122 cm)
• Diameter of dilution chamber:	8.4 in. (21.3 cm)
• Diameter of sample inlet tube:	1.68 in. (4.27 cm)
• Active dilution volume:	1,54 ft^3 (43,600 cm^3)
Flow	
• Sample flow (determined by inhalable particulate cyclone train):	0.6 ft^3/min (~ 17 liters/min)
• Sample velocity:	0.86 ft/sec (~ 27 cm/sec) at 302°F (150°C)
• Dilution airflow:	15 ft^3/min (425 liters/min)
• Dilution air velocity:	0.66 ft/sec (20 cm/sec)
• Dilution ratio:	~ 25:1 (up to 40:1 possible)
• Residence time:	6.2 sec
Gas conditions	
• Sample gas: T < 250°C; particles > 2.5 μm removed by cyclones	
• Dilution air: T = 21.1°C; relative humidity 24%, filtered ambient air	
Sample collection	
• Particulate collected on glass fiber filter	
• Optional impactor gives cuts at 0.5, 1.0, 2.0, and 4.0 μm	
• Optional extraction of diluted stream for sizing by optical counter, electrical mobility analyzer, condensation nuclei counter, etc.	

5.3 OPERATING PROCEDURE

The in-stack IP dual cyclone train is the intended precutter for the SDSS. This device is fully described in the "Procedures Manual for Inhalable Particulate Sampler Operation" cited earlier. The flow rate of stack gas entering the dilution system is determined by the necessity to obtain a D_{50} of 15 μm (50% collection efficiency at 15 μm) for the initial IP cyclone (SRI-X). This flow rate, which varies with temperature, can be determined from the experimental calibration data for the cyclone train. Nominally, 23 L/min (0.8 ft^3/min) is required for standard air at 150°C (300°F). Over the entire operating temperature range of the sampler, Cyclone SRI-III obtains 50% collection efficiency at 2.5 ± 0.5 μm for the flow rate determined by cyclone SRI-X. Particulate with aerodynamic diameter smaller than 2.5 μm (the fine particulate fraction) passes into the SDSS and provides the nuclei for the accumulation of condensable material in the dilution/cooling process.

Since the fine fraction of the in-stack particulate is collected along with the condensable emissions, a second dual cyclone IP train with a standard in-stack filter is used to measure simultaneously the in-stack particulate without condensation effects. The setup and operating procedures for both cyclone trains are essentially identical and are described in full in the SoRI procedures manual. In brief, the stack gas temperature, velocity, and composition are measured, and the gas viscosity calculated. Using calibration data for Cyclone X of the dual cyclone IP sampler, a flow rate is selected to obtain a D_{50} of 15 μm for this device. Nozzles are selected for isokinetic sampling, and the sampling trains, after warmup, are inserted at different points in the stack that are demonstrated not to have dramatically different loadings due to stratification of emissions. The protocol for the SDSS calls for sampling at a minimum of two points in a duct rather than a minimum of four as specified for the dual cyclone train. In either case, sampling points are chosen at the centroids of quadrants of the duct. When the minimum two-point measurements are taken, as they were in this test, the dual cyclone train is used to sample at one point while the SDSS is used at the other. In alternate runs, the sampling trains are switched, especially if stratification is noted.

After sampling, the cyclones are unloaded and the cyclone catches are collected according to the procedures manual for the dual cyclone train. The probe, heated hose, and sample gas inlet assembly of the SDSS are washed with a suitable solvent, usually acetone. The rinses are evaporated to dryness and the residue weighed as in EPA Reference Method 5. The probe wash weights are included with the SDSS filter in calculating the fine particulate plus condensable emissions fraction.

5.4 TEST CONDITIONS

The sampling crew from SoRI arrived on-site with the SDSS on Monday, October 5, and began setup. Due to delays in obtaining electrical power, the first run could not be made until Wednesday, October 7. A second run was performed on Thursday, October 8; in order to make up for the lost run on Tuesday, two runs were made on Friday, October 9.

All samples were taken from the outlet of the baghouse with the plant utilizing recycled paving material. A cross-section of the stack is shown in Figure 5.2. Samples were taken at points 2 and 4 of Figure 5.2. These points lie 105 cm (41.0 in.) from the entrance of each port along the diameter of the stack; in other words, at the centroids of the quadrants of the stack cross section which lie away from the baghouse. Stack velocities were measured at quadrant centroid points 1 to 4 and averaged to select sampling nozzle sizes. Gas composition (dry basis) was measured by Orsat and determined to be 15% O_2, 3% CO_2, and 82% N_2, respectively. Stack moisture as determined at the end of all IP runs varied from 14 to 19% by volume. Obviously, this figure will vary with production rate and the moisture content of the aggregate, but it was roughly constant except for Run 4. Other relevant variables are presented in Table 5.2.

To provide a "clean" substrate for any future chemical analysis, Zefluor Teflon membrane filters (GHIA, Inc.), 2-μm pore size, were used for all SDSS runs. For the in-stack backup filters on the conventional IP train, preweighed 47-mm glass fiber filters were employed. No pressure

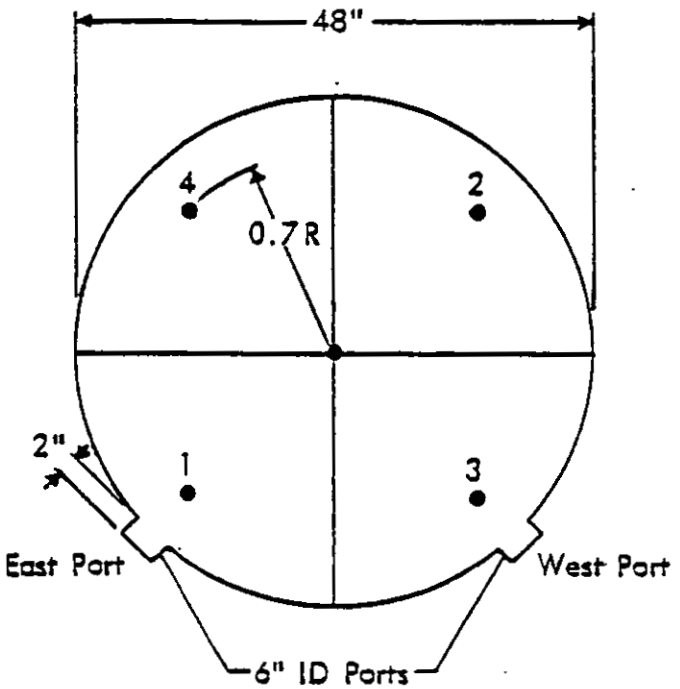


Figure 5.2. Cross section of baghouse outlet stack. Quadrants numbered as for condensables testing.

TABLE 5.2. RUN CONDITIONS FOR INHALABLE PARTICULATE AND STACK DILUTION SAMPLING SYSTEM TESTS AT BOWEN CONSTRUCTION COMPANY

Run No.	Start time	Date	Run time (min)	Stack temperature (°C)	Stack moisture volume (%)	Sample flow rate alm[a]	Sample flow rate (acfm)[b]	Sample volume dacm[c]	Sample volume (dscf)[d]	Average stack velocity m/sec[e]	Average stack velocity (ft/sec)[f]	Estimated total stack flow m^3/min[g]	Estimated total stack flow (acfm)[h]
1 IP	12:40 p.m.	10/7/81	155	154	18.3	20.72	(0.732)	1.765	(62.3)	18.4	(60.2)	1,290	45,400
1 SDSS			158			17.97	(0.635)	1.559	(55.0)				
2 IP	1:10 p.m.	10/8/81	146	154	19.9	21.39	(0.755)	1.681	(59.4)	21.5	(70.5)	1,500	53,100
2 SDSS			145			17.61	(0.622)	1.375	(48.6)				
3 IP	8:30 a.m.	10.9.81	180	152	18.7	21.38	(0.755)	2.104	(74.3)	21.7	(71.2)	1,520	53,700
3 SDSS			168			18.66	(0.659)	1.704	(60.2)				
4 IP	2:03 p.m.	10.9.81	106	149	14.0	18.73	(0.661)	1.155	(40.8)	21.4	(70.3)	1,500	53,000
4 SDSS			108			17.70	(0.625)	1.112	(39.3)				

[a] Actual liters per minute.

[b] Actual cubic feet per minute.

[c] Dry standard cubic meters.

[d] Dry standard cubic feet.

[e] Meters per second.

[f] Feet per second.

[g] Actual cubic meters per minute.

[h] Actual cubic feet per minute.

drop problems were noted with either filter. The SDSS filter from Run 1 was dropped after the run and was contaminated thus voiding the results. All other filters, including one blank filter of each type, were kept protected in covered containers.

5.5 RESULTS

The weights of the cyclone and filter catches are presented in Table 5.3. The cyclone catches were weighed after desiccation on a Cahn 27 balance at SoRI. All filter weights represent the results of replicate weighings in the controlled humidity weighing room at MRI. The variation of all replicate weighings was insignificant except for the loaded SDSS Teflon filters. The filters from Runs 2 to 4 showed a steady loss of weight with time, as shown in Figure 5.3. A blank SDSS filter which was taken to the test site and returned for weighing showed no such variation. For reasons discussed below, this loss was interpreted as evaporation of condensed organic compounds collected on the filter of the diluted stream. No similar weight loss was noted on the glass filters used for the in-stack cyclone train. The variations in the weights of these filters were within the 0.2-mg reliability of the Mettler AK160 balance used and were not monotonic with time. Over the 3- or 4-day weighing period, the glass filters were as likely to gain weight as to lose weight between reweighings. Thus, we concluded that the systematic weight loss was real and unique to the filter samples taken with the SDSS. Therefore, the weights reported for these filters in Table 5.3 are not averages, but rather the individual weights as measured 1 day after sampling. The rationale for this decision is discussed below.

Inspection of the data in Table 5.3 reveals that the two parallel cyclone trains collected roughly comparable amounts of dust for the runs in this test. For all pairs of cyclone catches except those in Run 1, the deviation from the mean is less than 30%. In Run 1, the SDSS cyclone X was significantly higher than the standard IP train with a deviation of 48% above the mean, but this is still within reasonable limits for simultaneous

TABLE 5.3. RAW WEIGHTS[a] FROM INHALABLE PARTCULATE STACK DILUTION SAMPLING SYSTEM TESTS AT BOWEN CONSTRUCTION COMPANY

Run No.	15 μm D_{50} cyclone SRI X	2.5 μm D_{50} cyclone SRI III	Uncorrected filter wt.	8% Corrected filter wt.	Wash	Total weight collected	Corrected total wt.
1 IP	10.21	2.77	2.8			15.78	
2 IP	31.53	1.58	2.5			35.61	
2 SDSS	20.51	2.77	14.69	15.87	5.4	43.37	44.55
3 IP	77.31	9.17	3.5			89.98	
3 SDSS	43.63	9.40	25.21	27.23	6.0	84.24	86.26
4 IP	11.20	2.47	2.8			16.47	
4 SDSS	16.09	2.37	24.64	26.61	4.0	47.1	49.07

[a] All weights in milligrams.

[b] Filter from SDSS Run 1 was contaminated.

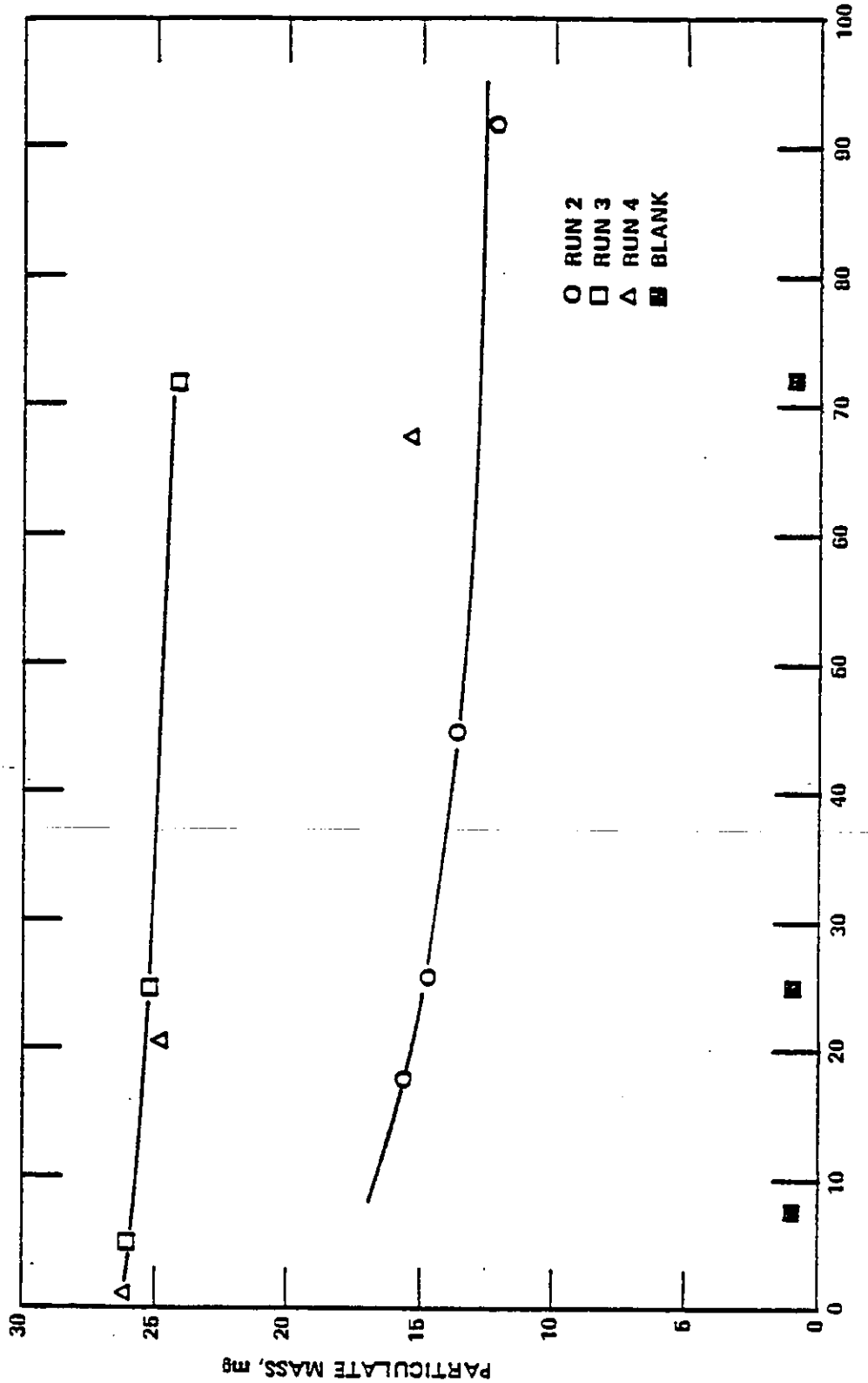


Figure 5.3. Variation of particulate mass on filter from stack dilution sampling system with time after sampling.

single-point samples. In contrast, the SDSS filter catches were factors of 6 to 9 higher than the in-stack filters even before the probe washes were included. This extra mass, coupled with the steady weight loss of the SDSS filters, indicates that the diluted flue gas contained a substantial amount of condensable material with enough volatility to reevaporate at room temperature. The most likely candidate species appear to be lower molecular weight aliphatic hydrocarbons from the asphalt mix, but analyses of the material would be necessary to confirm this speculation.

The evaporation of the SDSS filter samples results in some difficulty in assigning a unique loading to the filters. Obviously, the weights of the filters immediately after sampling would give best lower bounds to the samples, but there were technical problems in obtaining these data. First, it is not always desirable to take an appropriate balance to the field site. Second, it is customary to equilibrate filters for several hours in a constant humidity atmosphere or a desiccator before weighing to avoid artifacts due to adsorbed moisture. In this test, prompt weighings were available only for Run 4. However, for all three runs weighings were in the vicinity of 24 h after sampling. Since this was the earliest period after sampling for which accurate weights could be reported for all runs, and since the filters should have equilibrated with the weighing room atmosphere by the end of the day, these weights were chosen for Table 5.3.

To obtain a more realistic comparison of the weight losses of the three SDSS filters, all sample weights were normalized to the 1-day weights. These normalized data are presented in Figure 5.4. It is noteworthy that the relative weights of the three samples lie along the same curve. Extrapolating this curve, it is estimated that the filter catches immediately after sampling are 5 to 10% higher than the 24-h value and that up to 20% of this mass is lost after 4 days. To calculate mass concentrations at the time of emission, the 1-day weights given in Table 5.3 should be increased by approximately 8%.

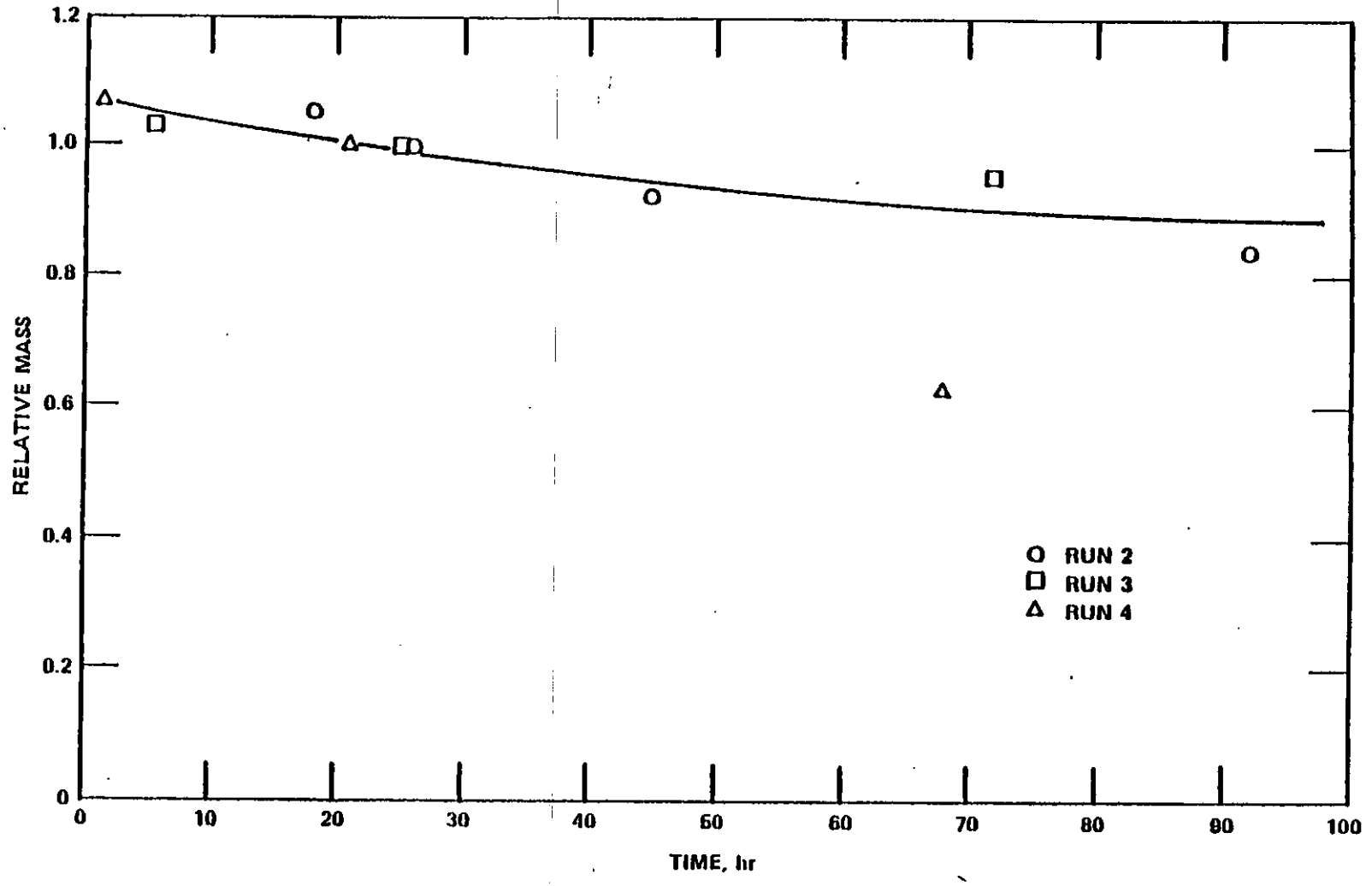


Figure 5.4. Relative variation of particulate mass on SDSS filter with time after sampling. All data for each run are normalized with respect to mass measured 1 day (21 to 26 h) after sampling.

The mass concentrations calculated from the test data are presented in Table 5.4. Concentrations have been calculated from the data in Tables 5.2 and 5.3. The fine particle plus condensable fraction has been corrected by the 8% fraction mentioned earlier, and the concentration of particles formed by condensation alone has been calculated by subtracting the fine particulate concentration measured by the standard IP train from the corresponding fraction from the SDSS data. This value, divided by the total emissions concentration measured in the SDSS, is tabulated as percent condensable. As can be seen, on the average 45% of the particulate measured in the SDSS at this source was formed by condensation.

The total mass concentrations in Table 5.4 are listed in metric and English units and have been converted to emissions factors in pounds per hour using the stack volume flow listed in Table 5.2. This number is based on a four-point velocity average rather than a full pitot traverse.

Table 5.5 presents the IP emission factors that were calculated from the condensables testing data. The IP emission factors were determined by first calculating a total mass emission factor (pounds/ton). The total mass emission factor was calculated by multiplying the ratio of the stack flow rate to the sampler flow rate by the total weight collected in the sampler and converting to pounds per hour. Pounds of emissions per ton of product were calculated by multiplying the average production rate (tons per hour) during the test period by the total emissions (pounds per hour). In order to calculate emission factors for >15, 2.5 to 15, and <2.5 μm (pounds per ton), the ratio of the individual stage weight (Table 5.3) to the total weight collected was multiplied by the total mass emission factor (pounds per ton).

One final word of caution: The condensable emission factors measured in the SDSS must not be equated with volatile organic carbon measurements made with other sampling trains. It has been demonstrated that the SDSS does not retain all the more volatile hydrocarbons that fall in the volatility range corresponding to the TCO fraction Level 1 organic analysis. These more volatile hydrocarbons will not be retained by the SDSS filter,

TABLE 5.4. PARTICULATE MASS CONCENTRATIONS (CONDENSABLES TESTING)

Run No.	Cyclone X > 15 μ mg/dscm[a]	Cyclone X > 15 μ gr/dscf[b]	Cyclone III 2.5-15 μm mg/dscm	Cyclone III 2.5-15 μm gr/dscf	Filter < 2.5 μm mg/dscm	Filter < 2.5 μm gr/dscf	Filter plus wash < 2.5 μm condensables mg/dscm	Filter plus wash < 2.5 μm condensables gr/dscf	% Condensables	Total emissions mg/dscm	Total emissions gr/dscf
1 IP	5.78	0.00252	1.57	0.000686	1.59	0.000694					
1 SDSS	19.03	0.00831	2.80	0.00122			-		-	8.94	0.0039
										-	-
2 IP	18.76	0.00819	0.94	0.00041	1.49	0.000651					
2 SDSS	14.92	0.00652	2.01	0.000878						21.19	0.0093
							15.78	0.00689	43.7	32.71	0.0143
3 IP	36.74	0.16	4.36	0.0019	1.66	0.000725					
3 SDSS	25.61	0.112	5.52	0.00241						42.76	0.0187
							19.79	0.00864	35.6	50.92	0.0223
4 IP	9.70	0.00424	2.14	0.000935	2.42	0.00106					
4 SDSS	14.47	0.00632	2.13	0.00093						14.26	0.0062
							27.81	0.0121	57.2	44.41	0.0194
Average IP	17.75	0.00775	2.25	0.000983	1.79	0.000782					
Average SDSS	18.51	0.00808	3.11	0.00136						21.79	0.0095
							21.13	0.00923	45.3	42.68	0.0187

[a] Milligrams per dry standard cubic meter.

[b] Grains per dry standard cubic foot.

(Data Reproduced in Table 3-14)

TABLE 5.5. EMISSION FACTORS (CONDENSABLES TESTING)

Run No.	Date	Ratio of total stack flow rate to sampler flow rate	Total emissions (lb/hr)	Average production rate[a] (tons/hr)	Total mass emission factor (lb/ton)	% Condensable	IP emission factor > 15 μm (lb/ton)	IP emission factor 2.5-15 μm (lb/ton)	IP emission factor < 2.5 μm (lb/ton)
1 IP	10/7/81	62,200	0.838	339	0.00247	-	0.0016	0.00043	0.00044
1 SDSS		71,500	-		-		-	-	-
2 IP	10/8/81	70,300	2.27	290	0.0078	43.7	0.0069	0.00035	0.00055
2 SDSS		85,400	3.47		0.012		0.0055	0.00075	0.0057
3 IP	10/9/81	71,100	4.70	322	0.0155	35.6	0.013	0.0016	0.00060
3 SDSS		81,500	5.54		0.0172		0.0087	0.0019	0.0066
4 IP	10/9/81	80,200	1.65	252	0.00655	57.2	0.0045	0.00098	0.0011
4 SDSS		84,800	5.10		0.0202		0.0066	0.00098	0.013
Avg IP				Avg IP	-0.0081	-45.5	-0.0065	-0.00004	-0.00067
Avg SDSS				Avg SDSS	-0.016		-0.0069	-0.0012	-0.0084

[a] Average production rate for test period except for Run 2 where the daily average was used to calculate the emission factor.

(Data Reproduced in Table 3-29)

as they will not remain in the condensed particulate in the actual plume of a stack. To obtain values of total organic emission, a sampling train such as the Source Assessment Sampling System is recommended. The present results are representative of the particulate emissions as they would exist in the near-stack ambient environment after emission, including that fraction of the volatile emissions found in the condensed phase.

APPENDIX H

COMPLETE LISTINGS OF JSKPRG, JSKRAW, AND JSKLOG

```
2 REM ----- PROGRAM "JSKPRG" -----
10 CLEAR 4000
12 REM ----- CLEAR REGISTERS FOR NEW RUN -----
15 OG=LOG(10):I2=0:XX=0:XD=0:X2=0:YP=0:ST=0:NZ=0:XM=0:LX=0:S1=0:YL=0:YM=0:DM=0:L1
=0:L2=0:L3=0:L4=0:L5=0
16 L6=0:K1=0:K2=0:K3=0:K4=0:K5=0:K6=0:JY=0:J9=0:IT=0:IJ=0:IM=0:I1=0
17 K2=0:I3=0:TL=0:KS=0:BA=0:SA=0:IQ=0:IX=0:I2=0:JX=0:IA=0:IC=0:IB=0
20 DIM XN(10),YO(10),X(53),A(16),B(4),CO(50,3),Y1(53),XD(15),XQ(10,50),YQ(10,50),
Y2(10),ID$(50),JX(50),JY(50),QQ(10,50),JQ(10),JW(10)
30 PRINT"PROGRAM SPLIN2 FROM FORTRAN ORIGINAL 02/22/82 V1"
31 LPRINT TAB(6)" ":LPRINT " ":LPRINT " ":LPRINT "                                SPLIN2
PROGRAM -  02/22/82 V1":LPRINT" ":LPRINT " "
39 REM ----- NUMBER OF DATA SETS AND REQUESTED OUTPUT -----
40 INPUT"ENTER # OF DATA SETS";QW
45 PRINT"ENTER D50'S IN INCREASING SIZE"
50 INPUT"ENTER NUMBER OF POINTS";NF
52 REM ----- INPUT PRODUCTION, EMISSION DATA -----
55 FOR QV=1 TO QW
58 INPUT"SET ID=";ID$(QV):INPUT "PROCESS WGT. RATE (TONS PRODUCED/HR)";JX(QV):INP
UT"TP EMISSION RATE (LB/HR)";JY(QV)
59 INPUT"ENTER PARTICLE DENSITY (g/cc)";JQ(QV):JW(QV)=SQR(JQ(QV))
60 FOR I=1 TO NF
70 INPUT"ENTER D50, CUM LOADING FOR EACH POINT";QQ(I,QV),YQ(I,QV):XQ(I,QV)=JW(QV)
*QQ(I,QV):NEXT I
80 PRINT"SET #";QV:NEXT QV
81 INPUT"ENTER # OF D50'S TO BE DETERMINED FOR ALL SETS";LA
82 FOR I=1 TO LA:INPUT"ENTER AERODYNAMIC D50";XD(I):NEXT I
83 FOR QV=1 TO QW:FOR I=1 TO NF:XN(I)=XQ(I,QV):YO(I)=YQ(I,QV):NEXT I
84 PRINT TIME$:LPRINT TAB(6)"TEST ID:  ";ID$(QV):LPRINT " ":LPRINT TAB(6)"INPUT
 DATA:        PROCESS WEIGHT RATE =";JX(QV)" TONS PROD./HR":LPRINT TAB(24)"TOTAL
 PARTICULATE EMISSION RATE =";JY(QV)" LB/HR":LPRINT TAB(24)"PARTICLE DENSITY ="
;JQ(QV)" G/CC"
85 LPRINT " ":LPRINT TAB(6)"MEASURED SIZE DISTRIBUTION":LPRINT " "
86 LPRINT TAB(6)" "CUT(um)         CUM. % < CUT":LPRINT " "
88 FOR I=1 TO NF:LPRINT TAB(6)" QQ(I,QV)," "          ";YO(I):NEXT I:LPRINT" ":LPRINT
" "
89 NN=8:RR=NN:N=4:R=N
90 NP=((NF-2)*N)+NN+1
91 JE=JY(QV)/JX(QV)
92 LPRINT " ":LPRINT TAB(6)"OUTPUT DATA:     TP EMISSION FACTOR = ";JE" LB/T  (
 "0.5*JE" KG/MT)":LPRINT" ":LPRINT " ":LPRINTTAB(41)"EMISSION FACTOR"
93 LPRINT TAB(6)"CUT (umA)     CUM. % < CUT      (LB/T)       (KG/MT)":LPRINT "
"
95 REM ----- SPLINE FIT OF MEASURED SIZE DISTRIBUTION -----
96 REM ----- BASIC TRANSLATION OF "SPLIN2" V1 02/22/82 -----
100 N2=NF-2
110 FOR I=1 TO N2
120 JJ=N-1
130 IF N2-I<0 THEN 150
140 JJ=N+2
150 M=(I-1)*N+1
160 X(M)=LOG(XN(I))/OG
170 Y1(M)=LOG(YO(I))/OG
180 XI=(LOG(XN(I+1))/OG-LOG(XN(I))/OG)/R
190 FOR II=1 TO 3
200 MM=I-1+II
210 B(II)=LOG(YO(MM))/OG
220 K=3*(II-1)
230 FOR J=1 TO 3
240 M3=I-1+J
250 A(K+J)=(LOG(XN(M3))/OG)^(II-1)
260 NEXT J:NEXT II
```

```
280 GOSUB 5000
290 FOR J=1 TO 2
300 SL=B(2)+2*B(3)*LOG(XN(I+J-1))/OG
310 IF SL>=0 THEN 350
320 B(2)=(LOG(YO(I+1)/YO(I)))/OG/(LOG(XN(I+1)/XN(I))/OG):B(1)=LOG(YO(I))/OG-B(2)*
LOG(XN(I))/OG
330 B(3)=0:J=2
350 NEXT J
360 FOR J=1 TO JJ
370 K=M+J
380 X(K)=LOG(XN(I))/OG+J*XI
390 Y1(K)=B(1)+B(2)*X(K)+B(3)*X(K)[2
400 NEXT J:NEXT I
410 FOR I=1 TO 3
420 K=3*(I-1)
430 FOR J=1 TO 3
440 M=1+(J-1)*N
450 A(K+J)=X(M)[(I-1)
460 NEXT J:NEXT I
470 FOR I=1 TO 3
480 M=1+(I-1)*N:B(I)=Y1(M):NEXT I
490 KS=0
500 GOSUB 5000
510 SL=B(2)+2*B(3)*X(1)
520 IF SL>=0 THEN 600
530 FOR I=1 TO 3:A(I)=1:NEXT I
540 A(4)=X(1)-(X(N+1)-X(1))
550 A(7)=A(4)[2
560 FOR I=1 TO 2:K=3*I:FOR J=2 TO 3
570 M=1+((J-2)*N):A(K+J)=X(M)[I:NEXT J:NEXT I
580 B(1)=Y1(1)
590 FOR I=2 TO 3:M=1+((I-2)*N):B(I)=Y1(M):NEXT I
595 KS=0:GOSUB 5000
600 FOR I=1 TO 3
610 CO(1,I)=B(I):NEXT I
615 II=1
620 IN=NP-NN-1
630 FOR I=II TO IN
640 JJ=I:B(1)=0
650 FOR J=2 TO 3
660 K=I-1
670 IF I=1 THEN K=I
680 B(1)=B(1)+(J-1)*(CO(K,J))*X(I)[(J-2)
690 NEXT J
700 B(2)=CO(K,1)
720 FOR J=2 TO 3:LET B(2)=B(2)+CO(K,J)*X(I)[(J-1):NEXT J
730 B(3)=Y1(I+2)
740 FOR J=1 TO 3:L=1+(J-1)*3:A(L)=(J-1)*X(I)[(J-2):NEXT J
750 FOR J=1 TO 3:K=J-1:KK=3*K:A(KK+2)=X(I)[K:NEXT J
760 FOR J=1 TO 3:K=J-1:KK=3*K:A(KK+3)=X(I+2)[K:NEXT J
770 KS=0
780 GOSUB 5000
790 FOR J=1 TO 3:CO(I,J)=B(J):NEXT J:NEXT I
800 IF JJ=(NP-1) THEN 1140
810 OS=LOG(XN(NF))/OG-LOG(XN(NF-1))/OG
820 XI=OS/RR
830 M=(NF-2)*N+1
840 XD=LOG(XN(NF-1))/OG:XM=LOG(XN(NF))/OG
850 NL=NP-NN
860 YL=10[Y1(NL)
870 DE=CO(IN,2)+CO(IN,3)*2*XD
880 PP=CO(IN,1)
890 FOR L=2 TO 3
900 PP=PP+CO(IN,L)*XD[(L-1):NEXT L
910 DM=DE*(10[PP)*2.302585
```

```
930 GOSUB 7000
935 N3=NN+2
940 FOR I=1 TO N3
950 J=M+I:X(J)=X(M)+I*XI
960 IF X(J)<ZS THEN 1000
970 Y1(J)=LOG(Y0(NF))/OG
980 GOTO 1100
1000 REM
1010 Y1(J)=B(1)
1020 FOR K=2 TO 4
1030 Y1(J)=Y1(J)+B(K)*X(J)^(K-1):NEXT K
1040 Y1(J)=LOG(Y1(J))/OG
1100 NEXT I
1110 II=NP-NN-2
1120 IN=NP-1
1130 GOTO 630
1140 I5=NP-1
1160 FOR I=1 TO LA
1180 D1=LOG(XD(I))/OG
1190 IS=NP-1
1200 FOR J=1 TO NP
1210 IF D1>X(J) THEN 1300
1220 IS=J-1
1230 J=NP
1300 NEXT J
1310 IF IS<1 THEN IS=1
1320 YD=CO(IS,1)+CO(IS,2)*D1+CO(IS,3)*D1*D1
1330 DY=10^YD
1340 LPRINT TAB(6);XD(I);TAB(20);DY;TAB(36);DY*JE/100;TAB(50);0.005*DY*JE
1350 NEXT I
1351 LPRINT TAB(6); " ":LPRINT TAB(6); "END OF TEST SERIES"
1360 LPRINT TAB(6);" ":LPRINT" ":NEXT QV
1365 PRINT TIME$
1370 PRINT "END OF RUN": END
5000 REM ROUTINE SIMQ
5010 TL=0
5020 KS=0
5030 J9=-3
5040 FOR J2=1 TO 3
5050 JY=J2+1
5060 J9=J9+3+1
5070 BA=0
5080 IT=J9-J2
5090 FOR I2=J2 TO 3
5100 IJ=IT+I2
5110 IF ABS(BA)-ABS(A(IJ))>=0 THEN 5150
5120 BA=A(IJ)
5130 IM=I2
5150 NEXT I2
5160 IF ABS(BA)-TL>0 THEN 5200
5170 KS=1
5180 J2=3:GOTO 5395
5200 I1=J2+3*(J2-2)
5210 IT=IM-J2
5220 FOR K2=J2 TO 3
5230 I1=I1+3:I3=I1+IT
5240 SA=A(I1)
5250 A(I1)=A(I3)
5260 A(I3)=SA
5270 A(I1)=A(I1)/BA:NEXT K2
5280 SA=B(IM)
5290 B(IM)=B(J2)
5300 B(J2)=SA/BA
5310 IF J2=3 THEN 5395
5320 IQ=3*(J2-1)
```

```
5340 IZ=IQ+IX
5350 IT=J2-IX
5360 FOR JX=JY TO 3
5370 XX=3*(JX-1)+IX
5380 JZ=XX+IT
5390 A(XX)=A(XX)-(A(IZ)*A(JZ)):NEXT JX
5392 B(IX)=B(IX)-B(J2)*A(IZ):NEXT IX
5395 NEXT J2
5398 IF KS=1 THEN 5500
5400 NY=3-1
5410 IT=3*3
5420 FOR J2=1 TO NY
5430 IA=IT-J2
5440 IB=3-J2
5450 IC=3
5460 FOR K2=1 TO J2
5470 B(IB)=B(IB)-A(IA)*B(IC)
5480 IA=IA-3
5490 IC=IC-1:NEXT K2:NEXT J2
5500 RETURN
7000 REM ROUTINE OSCFIT
7005 PRINT "7000";TIME$;
7010 NZ=0:ST=.1:XX=XM:LX=XM-XD
7020 S1=LX/99:G8=0
7030 NZ=NZ+1
7040 L1=XD-XX:L2=-L1:L3=L1*L1:L4=L2*L2
7050 L5=L3*L1:L6=L4*L2
7060 K1=YL/L3
7070 K2=-2*YL/L5
7080 K3=YM/L4
7090 K4=-2*YM/L6
7100 K5=DM/L3
7120 B(4)=K2+K4+K5
7130 B(3)=(K1+K3-(2*XX+XD)*(K2+K5)-(2*XD+XX)*(K4))
7140 B(2)=((K2+K5)*((XX*XX)+2*XD*XX)+(K4)*((XD*XD)+2*XD*XX))
7145 B(2)=B(2)-2*K1*XX-2*K3*XD
7150 B(1)=(K1*(XX*XX)+K3*(XD*XD)-XD*(XX*XX)*(K2+K5))-(XD*XD)*XX*(K4)
7160 X2=XD-S1
7170 FOR I2=1 TO 100
7180 X2=X2+S1
7190 IF X2>XX THEN 7250
7200 YP=3*B(4)*(X2*X2)+2*B(3)*X2+B(2)
7210 W4=0:IF YP<0 THEN XX=XX-ST:I2=100:W4=1
7250 NEXT I2
7260 IF W4=1 THEN W4=0:GOTO 7030
7300 IF NZ=1 THEN 7400
7310 XX=XX+ST:ST=ST/10
7320 IF ABS(ST)<1E-6 THEN 7350
7330 GOTO 7030
7350 XX=XX-10*ST
7400 ZS=XX:PRINT TIME$:RETURN
```

```
11 REM ----------PROGRAM "JSKRAW"----------------
5 CLS
10 CLEAR 4000
15 OG=LOG(10):I2=0:XX=0:XD=0:X2=0:YP=0:ST=0:NZ=0:XM=0:LX=0:S1=0:YL=0:YM=0:DM=0:L1
=0:L2=0:L3=0:L4=0:L5=0
16 L6=0:K1=0:K2=0:K3=0:K4=0:K5=0:K6=0:JY=0:J9=0:IT=0:IJ=0:IM=0:I1=0
17 K2=0:I3=0:TL=0:KS=0:BA=0:SA=0:IQ=0:IX=0:I2=0:JX=0:IA=0:IC=0:IB=0
20 DIM XN(10),YO(10),X(53),A(16),B(4),CO(50,3),Y1(53),XD(15),XQ(10,50),YQ(10,50),
Y2(10),ID$(50),JX(50),JY(50),QQ(10,50),JQ(10),JW(10)
30 PRINT"PROGRAM SPLIN2 FROM FORTRAN ORIGINAL 02/22/82 V1"
31 LPRINT " ":LPRINT " ":LPRINT TAB(22);"SPLIN2 PROGRAM - 02/22/82 V1":LPRINT " "

40 INPUT"ENTER # OF DATA SETS";QW
45 PRINT"ENTER D50'S IN INCREASING SIZE"
46 PRINT"The last entry inputted MUST be the largest particle diameter  using th
e density entered"
50 INPUT"ENTER NUMBER OF POINTS";NF
55 FOR QV=1 TO QW
58 INPUT"SET ID=";ID$(QV):INPUT "PROCESS WGT. RATE(tons pavins/hr)=";JX(QV):INPUT
 "TP EMISSION RATE (lb/hr)=";JY(QV)
59 INPUT "ENTER PARTICLE DENSITY (s/cc) ="; JQ(QV):JW(QV)=SQR(JQ(QV))
60 FOR I=1 TO NF
70 INPUT"ENTER D50, RAW LOADING FOR EACH POINT";QQ(I,QV),YQ(I,QV):XQ(I,QV)=JW(QV)
*QQ(I,QV):NEXT I
80 PRINT"SET #";QV:NEXT QV
81 INPUT"ENTER # OF D50'S TO BE DETERMINED FOR ALL SETS";LA
82 FOR I=1 TO LA:INPUT"ENTER AERODYNAMIC D50";XD(I):NEXT I
83 FOR QV=1 TO QW:FOR I=1 TO NF:XN(I)=XQ(I,QV):Y2(I)=YQ(I,QV):NEXT I
84 PRINT TIME$:LPRINT TAB(6);"TEST ID:  ";ID$(QV):LPRINT " ":LPRINT TAB(6);"INPUT
 DATA:       PROCESS WEIGHT RATE =";JX(QV);" TONS PROD. /HR":LPRINT TAB(24);"TOTA
L PARTICULATE EMISSION RATE =";JY(QV);"LB/HR":LPRINT TAB(24);"PARTICLE DENSITY ="
;JQ(QV);"G/CC "
85 LPRINT " ":LPRINT TAB(6);"MEASURED PARTICLE SIZE DISTRIBUTION":LPRINT " ":LPRI
NT TAB(6);"CUT (um)    RAW % < CUT     CUM. % < CUT":LPRINT " ":YO(0)=0:FOR I=1 T
O NF:YO(I)=YO(I-1)+Y2(I):NEXT I
86 FOR I=1 TO NF:YO(I)=YO(I)/YO(NF)*100
88 LPRINT TAB(6);QQ(I,QV) ,"   ";Y2(I),"     ";YO(I):NEXT I:LPRINT" "
89 NN=8:RR=NN:N=4:R=N
90 NP=((NF-2)*N)+NN+1
91 JE=JY(QV)/JX(QV)
92 LPRINT " ":LPRINT TAB(6);"OUTPUT DATA:    TP EMISSION FACTOR = ";JE;" LB/T  (
";0.5*JE;" KG/MT)":LPRINT " ":LPRINT " ":LPRINT TAB(39);"EMISSION FACTOR"
93 LPRINT TAB(6);"CUT (umA)    CUM. % < CUT     (LB/T)        (KG/MT)":LPRINT" "
100 N2=NF-2
110 FOR I=1 TO N2
120 JJ=N-1
130 IF N2-I<0 THEN 150
140 JJ=N+2
150 M=(I-1)*N+1
160 X(M)=LOG(XN(I))/OG
170 Y1(M)=LOG(YO(I))/OG
180 XI=(LOG(XN(I+1))/OG-LOG(XN(I))/OG)/R
190 FOR II=1 TO 3
200 MM=I-1+II
210 B(II)=LOG(YO(MM))/OG
220 K=3*(II-1)
230 FOR J=1 TO 3
240 M3=I-1+J
250 A(K+J)=(LOG(XN(M3))/OG)^(II-1)
260 NEXT J:NEXT II
270 KS=0
280 GOSUB 5000
290 FOR J=1 TO 2
```

```
310 IF SL>=0 THEN 350
320 B(2)=(LOG(Y0(I+1)/Y0(I)))/OG/(LOG(XN(I+1)/XN(I))/OG):B(1)=LOG(Y0(I))/OG-B(2)*
LOG(XN(I))/OG
330 B(3)=0:J=2
350 NEXT J
360 FOR J=1 TO JJ
370 K=M+J
380 X(K)=LOG(XN(I))/OG+J*XI
390 Y1(K)=B(1)+B(2)*X(K)+B(3)*X(K)C2
400 NEXT J:NEXT I
410 FOR I=1 TO 3
420 K=3*(I-1)
430 FOR J=1 TO 3
440 M=1+(J-1)*N
450 A(K+J)=X(M)C(I-1)
460 NEXT J:NEXT I
470 FOR I=1 TO 3
480 M=1+(I-1)*N:B(I)=Y1(M):NEXT I
490 KS=0
500 GOSUB 5000
510 SL=B(2)+2*B(3)*X(1)
520 IF SL>=0 THEN 600
530 FOR I=1 TO 3:A(I)=1:NEXT I
540 A(4)=X(1)-(X(N+1)-X(1))
550 A(7)=A(4)C2
560 FOR I=1 TO 2:K=3*I:FOR J=2 TO 3
570 M=1+((J-2)*N):A(K+J)=X(M)CI:NEXT J:NEXT I
580 B(1)=Y1(1)
590 FOR I=2 TO 3:M=1+((I-2)*N):B(I)=Y1(M):NEXT I
595 KS=0:GOSUB 5000
600 FOR I=1 TO 3
610 CO(1,I)=B(I):NEXT I
615 II=1
620 IN=NP-NN-1
630 FOR I=II TO IN
640 JJ=I:B(1)=0
650 FOR J=2 TO 3
660 K=I-1
670 IF I=1 THEN K=I
680 B(1)=B(1)+(J-1)*(CO(K,J))*X(I)C(J-2)
690 NEXT J
700 B(2)=CO(K,1)
720 FOR J=2 TO 3:LET B(2)=B(2)+CO(K,J)*X(I)C(J-1):NEXT J
730 B(3)=Y1(I+2)
740 FOR J=1 TO 3:L=1+(J-1)*3:IFJ=1THENA(L)=0ELSEA(L)=(J-1)*X(I)C(J-2)
745 NEXT J
750 FOR J=1 TO 3:K=J-1:KK=3*K:A(KK+2)=X(I)CK:NEXT J
760 FOR J=1 TO 3:K=J-1:KK=3*K:A(KK+3)=X(I+2)CK:NEXT J
770 KS=0
780 GOSUB 5000
790 FOR J=1 TO 3:CO(I,J)=B(J):NEXT J:NEXT I
800 IF JJ=(NP-1) THEN 1140
810 OS=LOG(XN(NF))/OG-LOG(XN(NF-1))/OG
820 XI=OS/RR
830 M=(NF-2)*N+1
840 XD=LOG(XN(NF-1))/OG:XM=LOG(XN(NF))/OG
850 NL=NP-NN
860 YL=10CY1(NL)
870 DE=CO(IN,2)+CO(IN,3)*2*XD
880 PP=CO(IN,1)
890 FOR L=2 TO 3
900 PP=PP+CO(IN,L)*XDC(L-1):NEXT L
910 DM=DE*(10CPP)*2.302585
920 YM=Y0(NF)
930 GOSUB 7000
```

```
940 FOR I=1 TO N3
950 J=M+I:X(J)=X(M)+I*XI
960 IF X(J)<ZS THEN 1000
970 Y1(J)=LOG(YO(NF))/OG
980 GOTO 1100
1000 REM
1010 Y1(J)=B(1)
1020 FOR K=2 TO 4
1030 Y1(J)=Y1(J)+B(K)*X(J)C(K-1):NEXT K
1040 Y1(J)=LOG(Y1(J))/OG
1100 NEXT I
1110 II=NP-NN-2
1120 IN=NP-1
1130 GOTO 630
1140 IS=NP-1
1160 FOR I=1 TO LA
1180 D1=LOG(XD(I))/OG
1190 IS=NP-1
1200 FOR J=1 TO NP
1210 IF D1>X(J) THEN 1300
1220 IS=J-1
1230 J=NP
1300 NEXT J
1310 IF IS<1 THEN IS=1
1320 YD=CO(IS,1)+CO(IS,2)*D1+CO(IS,3)*D1*D1
1330 DY=10^YD
1340 LPRINT TAB(6);XD(I);TAB(20);DY;TAB(36);DY*JE/100;TAB(50);0.005*DY*JE
1350 NEXT I
1360 LPRINT" ":LPRINT" ":NEXT QV
1362 LPRINT TAB(6);"END OF TEST SERIES"
1365 PRINT TIME$
1370 PRINT "END OF RUN": END
5000 REM ROUTINE SIMQ
5010 TL=0
5020 KS=0
5030 J9=-3
5040 FOR J2=1 TO 3
5050 JY=J2+1
5060 J9=J9+3+1
5070 BA=0
5080 IT=J9-J2
5090 FOR I2=J2 TO 3
5100 IJ=IT+I2
5110 IF ABS(BA)-ABS(A(IJ))>=0 THEN 5150
5120 BA=A(IJ)
5130 IM=I2
5150 NEXT I2
5160 IF ABS(BA)-TL>0 THEN 5200
5170 KS=1
5180 J2=3:GOTO 5395
5200 I1=J2+3*(J2-2)
5210 IT=IM-J2
5220 FOR K2=J2 TO 3
5230 I1=I1+3:I3=I1+IT
5240 SA=A(I1)
5250 A(I1)=A(I3)
5260 A(I3)=SA
5270 A(I1)=A(I1)/BA:NEXT K2
5280 SA=B(IM)
5290 B(IM)=B(J2)
5300 B(J2)=SA/BA
5310 IF J2=3 THEN 5395
5320 IQ=3*(J2-1)
5330 FOR IX=JY TO 3
5340 IZ=IQ+IX
```

```
5360 FOR JX=JY TO 3
5370 XX=3*(JX-1)+IX
5380 JZ=XX+IT
5390 A(XX)=A(XX)-(A(IZ)*A(JZ)):NEXT JX
5392 B(IX)=B(IX)-B(J2)*A(IZ):NEXT IX
5395 NEXT J2
5398 IF KS=1 THEN 5500
5400 NY=3-1
5410 IT=3*3
5420 FOR J2=1 TO NY
5430 IA=IT-J2
5440 IB=3-J2
5450 IC=3
5460 FOR K2=1 TO J2
5470 B(IB)=B(IB)-A(IA)*B(IC)
5480 IA=IA-3
5490 IC=IC-1:NEXT K2:NEXT J2
5500 RETURN
7000 REM ROUTINE OSCFIT
7005 PRINT "7000";TIME$;
7010 NZ=0:ST=.1:XX=XM:LX=XM-XO
7020 S1=LX/99:G8=0
7030 NZ=NZ+1
7040 L1=XO-XX:L2=-L1:L3=L1*L1:L4=L2*L2
7050 L5=L3*L1:L6=L4*L2
7060 K1=YL/L3
7070 K2=-2*YL/L5
7080 K3=YM/L4
7090 K4=-2*YM/L6
7100 K5=OM/L3
7120 B(4)=K2+K4+K5
7130 B(3)=(K1+K3-(2*XX+XO)*(K2+K5)-(2*XO+XX)*(K4))
7140 B(2)=((K2+K5)*((XX*XX)+2*XO*XX)+(K4)*((XO*XO)+2*XO*XX))
7145 B(2)=B(2)-2*K1*XX-2*K3*XO
7150 B(1)=(K1*(XX*XX)+K3*(XO*XO)-XO*(XX*XX)*(K2+K5))-(XO*XO)*XX*(K4)
7160 X2=XO-S1
7170 FOR I2=1TO 100
7180 X2=X2+S1
7190 IF X2>XX THEN 7250
7200 YP=3*B(4)*(X2*X2)+2*B(3)*X2+B(2)
7210 W4=0:IF YP<0 THEN XX=XX-ST:I2=100:W4=1
7250 NEXT I2
7260 IF W4=1 THEN W4=0:GOTO 7030
7300 IF NZ=1 THEN 7400
7310 XX=XX+ST:ST=ST/10
7320 IF ABS(ST)<1E-6 THEN 7350
7330 GOTO 7030
7350 XX=XX-10*ST
7400 ZS=XX:PRINT TIME$:RETURN
```

```
1 REM *=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=
2 REM
3 REM       Program "JSKLOG",10/04/82
4 REM For use in the asphalt category report
5 REM in those cases that a log-normal size distri-
6 REM bution is used to characterize data.
7 REM
8 REM *=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=
10 CLEAR 4000
15 OG=LOG(10):I2=0:XX=0:XD=0:X2=0:YP=0:ST=0:NZ=0:XM=0:LX=0:S1=0:YL=0:YM=0:DM=0:L1
=0:L2=0:L3=0:L4=0:L5=0
16 L6=0:K1=0:K2=0:K3=0:K4=0:K5=0:K6=0:JY=0:J9=0:IT=0:IJ=0:IM=0:I1=0
17 K2=0:I3=0:TL=0:KS=0:BA=0:SA=0:IQ=0:IX=0:I2=0:JX=0:IA=0:IC=0:IB=0
20 DIM XN(10),YO(10),X(53),A(16),B(4),CO(50,3),Y1(53),XD(15),XQ(10,50),YQ(10,50),
Y2(10),ID$(50),JX(50),JY(50),QQ(10,50),JQ(10),JW(10)
30 PRINT"PROGRAM SPLIN2 FROM FORTRAN ORIGINAL 02/22/82 V1"
31 LPRINT TAB(6); " ":LPRINT " ":LPRINT " ":LPRINT "                    SPLIN2
PROGRAM -  02/22/82 V1":LPRINT" ":LPRINT " "
40 INPUT"ENTER # OF DATA SETS";QW
45 PRINT"ENTER D50'S IN INCREASING SIZE"
50 INPUT"ENTER NUMBER OF POINTS";NF
55 FOR QV=1 TO QW
58 INPUT"SET ID=";ID$(QV):INPUT "PROCESS WGT. RATE (TONS PRODUCED/HR)";JX(QV):INP
UT"TP EMISSION RATE (LB/HR)";JY(QV)
59 INPUT"ENTER PARTICLE DENSITY (g/cc)";JQ(QV):JW(QV)=SQR(JQ(QV))
60 FOR I=1 TO NF
70 INPUT"ENTER D50, CUM LOADING FOR EACH POINT";QQ(I,QV),YQ(I,QV):XQ(I,QV)=JW(QV)
*QQ(I,QV):NEXT I
80 PRINT"SET #";QV:NEXT QV
81 INPUT"ENTER # OF D50'S TO BE DETERMINED FOR ALL SETS";LA
82 FOR I=1 TO LA:INPUT"ENTER AERODYNAMIC D50";XD(I):NEXT I
83 FOR QV=1 TO QW:FOR I=1 TO NF:XN(I)=XQ(I,QV):YO(I)=YQ(I,QV):NEXT I
84 PRINT TIME$:LPRINT TAB(6);"TEST ID:  ";ID$(QV):LPRINT " ":LPRINT TAB(6);"INPUT
 DATA:        PROCESS WEIGHT RATE =";JX(QV);" TONS PROD./HR":LPRINT TAB(24);"TOTAL
 PARTICULATE EMISSION RATE =";JY(QV);" LB/HR":LPRINT TAB(24);"PARTICLE DENSITY ="
;JQ(QV);" G/CC"
85 LPRINT " ":LPRINT TAB(6);"MEASURED SIZE DISTRIBUTION":LPRINT " "
86 LPRINT TAB(6); "CUT(um)       CUM. % < CUT":LPRINT " "
88 FOR I=1 TO NF:LPRINT TAB(6); QQ(I,QV),"          ";YO(I):NEXT I:LPRINT" ":LPRINT
" "
89 NN=8:RR=NN:N=4:R=N
90 NP=((NF-2)*N)+NN+1
91 JE=JY(QV)/JX(QV)
92 LPRINT " ":LPRINT TAB(6);"OUTPUT DATA:    TP EMISSION FACTOR = ";JE; " LB/T  (
 ";0.5*JE;" KG/MT)":LPRINT" ":LPRINT " ":LPRINTTAB(41);"EMISSION FACTOR"
93 LPRINT TAB(6);"CUT (umA)      CUM. % < CUT        (LB/T)        (KG/MT)":LPRINT "
"
94 FORQ%=1TOLA:PRINT"LOG-NORMAL % <";XD(Q%):INPUT" umA";DY:LPRINT TAB(6);XD(Q%);T
AB(20);DY;TAB(36);DY*JE/100;TAB(50);0.005*DY*JE:NEXT Q%
95 LPRINT "THIS DATA SET WAS FIT TO A LOG-NORMAL SIZE DISTRIBUTION":END
```

APPENDIX I

DESCRIPTION OF TI-59 PROGRAM TO COMPUTE LOG-NORMAL PARTICLE SIZE DISTRIBUTION

Particle size data fitting a log-normal distribution yields a straight line when plotted on log-probability graph paper. To graphically determine the mass fraction of particles smaller than 15 μm in diameter, the data points would have to be plotted. Then, the best-fit line would be drawn through the data points and the IP fraction determined. Such a graphical approach is time consuming and requires a subjective judgment in drawing the best-fit line through the data points.

An analytical technique utilizing the TI-59 programmable calculator was developed as part of this study. The program transforms both coordinates into a linear format, as shown in Figure 6, and then performs a standard linear regression analysis to find the slope and intercept of the least squares line fit to the data. The ordinate is linearized by taking the logarithm of the aerodynamic particle diameter. The abscissa or the probability function is represented by the integral

$$F = \int_{-\infty}^{x} \frac{e^{-t^2/2}}{\sqrt{2\pi}}\, dt$$

This integral can not be solved explicitly, but can be approximated by

$$0 < F \leq 0.5 \quad x = -t + \frac{c_0 + c_1 t + c_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^3} + \epsilon(F), \text{ where } t = \sqrt{\ln(1/F^2)} \text{ and}$$

$$0.5 < F < 1.0 \quad x = t - \frac{c_0 + c_1 t + c_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^3} + \epsilon(F), \text{ where } t = \sqrt{\ln(1/(1-F))^2}\ .$$

The constants needed for the probability function approximation are given in Table A-1.

TABLE A-1. CONSTANTS USED IN THE LOG NORMAL DATA ANALYSIS[16]

$b_1 = 0.31938153$	$c_0 = 2.515517$	$d_1 = 1.432788$
$b_2 = -0.356563782$	$c_1 = 0.802853$	$d_2 = 0.189269$
$b_3 = 1.781477937$	$c_2 = 0.010328$	$d_3 = 0.001308$
$b_4 = -1.821255978$		
$b_5 = 1.330274429$	$r = 0.2316419$	
$\lvert\epsilon(x)\rvert < 7.5 \times 10^{-8}$		$\lvert\epsilon(F)\rvert < 4.5 \times 10^{-4}$

Once the data points are transformed to linear coordinates, the standard linear regression function of the TI-59 is used to determine the slope and intercept of the least squares line fit through the data points. The mass median diameter is the anti-log of the y-intercept, as shown in Figure 6, and the geometric standard deviation is the anti-log of the slope. The linear correlation coefficient is also calculated.

To find the mass fraction of particles smaller than 15 μm, the log of 15 (y-coordinate) is entered and the corresponding value of the x-coordinate is computed using the least squares line previously determined. This program can be modified very easily if the mass fraction for another particle cut size is desired. The computed x-coordinate value is then converted back to a mass fraction using the following formulas:

$$x \leq 0 \quad F = f(x)[b_1 t + b_2 t^2 + b_3 t^3 + b_4 t^4 + b_5 t^5] + \epsilon(x)$$

$$x > 0 \quad F = 1 - f(x)[b_1 t + b_2 t^2 + b_3 t^3 + b_4 t^4 + b_5 t^5] + \epsilon(x)$$

where $$f(x) = \frac{1}{\sqrt{2\pi}} e^{-x^2/2} \quad \text{and} \quad t = \frac{1}{1 + r|x|} .$$

The constants for the formula are presented in Table A-1. Appendix B contains the log-normal distribution program used for analysis of the particle size test data.

The log-normal method is a useful procedure for interpolating between points as well as extrapolating beyond the measured range of the particle size distribution. It is common to find deviations from log-normality at the extremes of the size distribution. There are limitations of the log-normal method; however, this procedure facilitates the extrapolation needed to arrive at a mass fraction less than 15 μm, from measured particle size distribution data.

TITLE LOG-NORMAL DISTRIBUTION PAGE 1 OF 2

PROGRAMMER M M DATE 12-28-75

TI Programmable **Program Record**

Partitioning (Op 17) [ ] Library Module Master Library Printer _____ Cards 1 (BOTH SIDES)

PROGRAM DESCRIPTION

THIS PROGRAM FITS A LINE THROUGH DATA POINTS OBEYING A LOG-NORMAL DISTRIBUTION. THE ORDINATE (PARTICLE DIAMETER) IS TRANSFORMED TO A LINEAR SCALE WITH COMMON LOGS AND THE ABSCISSA (CUMULATIVE MASS FRACTION LESS THAN A GIVEN DIAMETER) IS TRANSFORMED BY THE EQUATION $P(x) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{x} e^{-x^2/2}\, dx$. THE PROGRAM GIVES THE MASS MEDIAN DIAMETER (INCREASE LOG OF Y INTERCEPT) AND THE GEOMETRIC STANDARD DEVIATION (ANTI-LOG OF SLOPE) AS WELL AS THE CORELATION COEFFICIENT, R.

USER INSTRUCTIONS

STEP	PROCEDURE	ENTER	PRESS			DISPLAY
1.	READ CARD		CLR	FEED SIDE	1	1
			CLR	FEED SIDE	2	2
2	STORE CONSTANTS & PREPARE FOR 1ST DATA POINT		E			0
3	ENTER DATA POINT: ENTER DIAMETER IN MICRONS		R/S			LOG D (Y COORDINATE)
	ENTER F AS FRACTION (NOT %)		R/S			(X COORDINATE)
	ENTER WEIGHING FACTOR (INTEGER ≥ 1)		R/S			CUMULATE = # OF DATA POINTS
4	FOR NEXT DATA POINT REPEAT STEP 3					
5.	COMPUTE: MASS MEDIAN DIAMETER		B			MMD
	GEO STANDARD DEVIATION		R/S			GSD
	CORELATION COEFFICIENT		R/S			R
6	COMPUTE: FRACTION LESS THAN 15 μm		C			F(<15μm)
7	COMPUTE: FRACTION LESS THAN DINPUT DINPUT		D			F(<DINPUT)
8.	FOR NEW SET OF DATA (NEW LINE)		A			0
	THEN GO TO STEP 3 TO ENTER DATA					

USER DEFINED KEYS	DATA REGISTERS (INV Ins)		LABELS (Op 08)
A RESTART [CLEAR SUMMATION REGISTERS]	10 USED	20 C_1	INV Ins CE CLR x≥t x²
B MMD, GSD, R	11 USED	21 C_2	√x 1/x STO RCL SUM yˣ
C F(<15μm)	12 USED	22 d_1	EE ( ) ÷ GTO ×
D F(< DINPUT)	13	23 d_2	SBR − RST + R/S ·
E START [STORE CONSTANTS, CLEAR REGISTERS]	14	24 d_3	+/− = CLR INV Nˣ Eˣ
A'	15	25 r	Tan Cos P→R Sin Ln CMs
B'	16	26 b_1	Cot Sin R→P Cos Log Dsz
C'	30 b_5	27 b_2	Lrn Σ− Σ+ n x̄ Gto Stop
D'	18	28 b_3	Int Dsz x≥t Int Pause Rtn
E'	19 C_0	29 b_4	Abs Exc

FLAGS	0	1	2	3	4	5	6	7	8	9

1014966-1

TITLE LOG-NORMAL DISTRIBUTION PAGE 2 OF 2

PROGRAMMER [illegible] DATE 12-28-78

TI Programmable **Program Record**

Partitioning (Op 17) | | Library Module _____ Printer _____ Cards _____

PROGRAM DESCRIPTION

THIS PROCEDURE IS EQUIVALENT TO GRAPHICALLY SOLVING THE PROBLEM USING LOG-PROBABILITY PAPER.

USER INSTRUCTIONS

STEP	PROCEDURE	ENTER	PRESS	DISPLAY
	COORDINATE TRANSFORMATION USE FOLLOWING NUMERICAL APPROXIMATIONS:			
	$0 < F \leq 0.5$ $\quad x = -t + \frac{c_0 + c_1 t + c_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^3} + \epsilon(F)$			$t = \sqrt{\ln \frac{1}{F^2}}$ $\quad \lvert\epsilon(F)\rvert < 4.5 \times 10^{-4}$
	$0.5 < F < 1.0$ $\quad x = +\frac{c_0 + c_1 t + c_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^3} + \epsilon(F)$			$t = \sqrt{\ln \frac{1}{(1-F)^2}}$
	$x \leq 0$ $\quad F = f(x)\left[b_1 t + b_2 t^2 + b_3 t^3 + b_4 t^4 + b_5 t^5\right] + \epsilon(x)$			$f(x) = \frac{1}{\sqrt{2\pi}} e^{-x^2/2}$
	$x > 0$ $\quad F = 1 - f(x)\left[b_1 t + b_2 t^2 + b_3 t^3 + b_4 t^4 + b_5 t^5\right] + \epsilon(x)$			$t = \frac{1}{1 + r\lvert x\rvert}$
				$\lvert\epsilon(x)\rvert < 7.5 \times 10^{-8}$
	REF:			

USER DEFINED KEYS	DATA REGISTERS (INV INT)		LABELS (Op 08)
A	0	0	
B	1	1	
C	2	2	
D	3	3	
E	4	4	
A'	5	5	
B'	6	6	
C'	7	7	
D'	8	8	
E'	9	9	

FLAGS	0	1	2	3	4	5	6	7	8	9

TITLE LOG-NORMAL DISTRIBUTION PAGE 1 OF 2

PROGRAMMER [illegible] DATE 12-23-79

TI Programmable **Coding Form**

LOC	CODE	KEY	COMMENTS
	76	2nd LBL	CLEAR REGIS-
	11	A	TERS FOR
	36	2nd PGM	NEW SET
	01	01	OF DATA
	71	SBR	
	25	CLR	
	76	2nd LBL	
	16	2nd A'	
	91	R/S	ENTER Di
	28	2nd LOG	IN MICRONS
1	42	STO	
	13	13	
	91	R/S	ENTER Fi
	71	SBR	AS *
	33	X2	FRACTION
	32	X⇄T	
	43	RCL	
	13	13	
	28	2nd LOG	
	43	RCL	DISPLAY No.
2	03	03	OF DATA
	61	GTO	POINTS + PREPARE
	16	2nd A'	FOR NEW DATA POINT
	76	2nd LBL	COMPUTE
	12	B	Y-INTERCEPT
	29	2nd CP	& CONVERT
	12	12	TO MASS
	22	INV	MEDIAN DIAM.
	28	2nd LOG	
	91	R/S	
3	32	X⇄T	COMPUTE SLOPE
	22	INV 2nd LOG	& CONVERT TO
	91	R/S	STD. GEO. DEV.
	29	2nd CP	DISPLAY
	13	13	CORRELATION
	91	R/S	COEFFICIENT
	76	2nd LBL	COMPUTE
	13	C	FRACTION
	01	1	LESS THAN
	05	5	15 μm
4	76	2nd LBL	
	19	2nd D'	
	28	2nd LOG	
	29	2nd CP	
	15	15	
	71	SBR	
	35	1/X	
	91	R/S	
	76	2nd LBL	COMPUTE
	14	D	FRACTION LESS
5	61	GTO	THAN ENTERED
	18	2nd C'	DIAM
	76	2nd LBL	SUBROUTINE
	23	X2	X2 CONVERTS
	42	STO	Fi (FRACTION

LOC	CODE	KEY	COMMENTS
	07	07	INTO A
	93	.	LINEAR
	05	5	X-COORDINATE
	32	X⇄T	
	43	RCL	
6	07	07	
	17	2nd X2	
	34	√	
	43	RCL	
	07	07	
	35	1/X	
	33	X2	
	23	Ln	
	34	√	
	42	STO	
7	08	08	
	71	SBR	
	32	X⇄T	
	61	GTO	
	42	STO	
	76	2nd LBL	
	34	√	
	43	RCL	
	07	07	
	94	+/-	
8	85	+	
	01	1	
	95	=	
	35	1/X	
	33	X2	
	23	Ln	
	34	√	
	42	STO	
	05	05	
	71	SBR	
9	32	X⇄T	
	94	+/-	
	76	2nd LBL	
	42	STO	
	42	STO	
	09	09	
	92	INV SBR	
	76	2nd LBL	SUBROUTINE
	32	X⇄T	X⇄T IS
	01	1	CALLED BY
10	85	+	SUBROUTINE
	43	RCL	X2
	22	22	
	65	X	
	43	RCL	
	05	05	
	85	+	
	43	RCL	
	09	09	

LOC	CODE	KEY	COMMENTS
11	65	X	
	43	RCL	
	23	23	
	85	+	
	43	RCL	
	08	08	
	33	X2	
	65	X	
	43	RCL	
	08	08	
12	65	X	
	43	RCL	
	24	24	
	95	=	
	42	STO	
	10	10	
	43	RCL	
	19	19	
	85	+	
	43	RCL	
13	08	08	
	65	X	
	43	RCL	
	20	20	
	85	+	
	43	RCL	
	08	08	
	33	X2	
	65	X	
	43	RCL	
14	21	21	
	95	=	
	55	÷	
	43	RCL	
	10	10	
	75	=	
	45	−	
	43	RCL	
	09	09	
	95	=	
15	92	INV SBR	
	76	2nd LBL	SUBROUTINE
	35	1/X	1/X CONVERTS
	42	STO	THE LINEAR
	10	10	X-COORDINATE
	50	2nd |X|	BACK TO
	65	X	A FRACTION
	43	RCL	
	25	25	
	95	=	

MERGED CODES

62 Prd Ind		72 STO Ind		83 GTO Ind	
63 Exc Ind		73 RCL Ind		84 Op Ind	
64 Prd Ind		74 SUM Ind		92 INV SBR	

TEXAS INSTRUMENTS INCORPORATED

TITLE Log-Normal Distribution PAGE 2 OF 2

PROGRAMMER JM JM DATE 12-28-78

TI Programmable Coding Form

LOC	CODE	KEY	COMMENTS
16	31	1	
	95	=	
	35	1/x	
	42	STO	
	11	11	
	53	(	
	43	RCL	
	20	20	
	65	X	
	43	RCL	
17	11	11	
	85	+	
	43	RCL	
	27	27	
	65	X	
	43	RCL	
	11	11	
	33	X^2	
	85	+	
	43	RCL	
18	28	28	
	65	X	
	43	RCL	
	11	11	
	33	X^2	
	65	X	
	43	RCL	
	11	11	
	55	÷	
	43	RCL	
19	29	29	
	65	X	
	43	RCL	
	11	11	
	33	X^2	
	33	X^2	
	85	+	
	43	RCL	
	30	30	
	65	X	
20	43	RCL	
	11	11	
	33	X^2	
	33	X^2	
	65	X	
	43	RCL	
	11	11	
	54	)	
	42	STO	
	11	11	
21	53	(	
	53	(	
	43	RCL	
	10	10	
	33	X^2	

LOC	CODE	KEY	COMMENTS
	55	÷	
	02	2	
	94	+/−	
	95	=	
	22	INV	
22	23	$\ln x$	
	54	)	
	55	÷	
	53	(	
	02	2	
	65	X	
	89	2^{nd} π	
	54	)	
	34	$\sqrt{\ }$	
	54	)	
23	65	X	
	43	RCL	
	11	11	
	95	=	
	42	STO	
	12	12	
	00	0	
	32	$X \rightleftarrows t$	
	43	RCL	
	10	10	
24	22	INV	
	77	2^{nd} X≥t	
	53	(	
	01	1	
	75	−	
	43	RCL	
	12	12	
	95	=	
	42	STO	
	12	12	
25	76	2^{nd} Lbl	
	53	(	
	43	RCL	
	12	12	
	92	INV SBR	
	76	2^{nd} Lbl	STORAGE OF
	15	E	CONSTANTS
		2.515517	
288	42 19	STO 19	C_0
		0.802853	
297	42 20	STO 20	C_1
		0.010328	
306	42 21	STO 21	C_2
		1.432788	
316	42 22	STO 22	d_1
		0.189269	
325	42 23	STO 23	d_2
		0.001308	
334	42 24	STO 24	d_3
		0.001419	

LOC	CODE	KEY	COMMENTS
344	42 25	STO 25	t
		0.3193915 3	
355	42 26	STO 26	b_1
		0.3565641782	
367	94	+/−	
368	4227	STO 27	b_2
		1.781477937	
381	42 28	STO 28	b_3
		1.821255978	
394	94	+/−	
395	4229	STO 29	b_4
		1.330274429	
408	42 30	STO 30	b_5
	61	GTO	
415	11	A	

MERGED CODES

62 Prd Int	72 STO Int	83 GTO Int
63 Exc Int	73 RCL Int	84 Σ+ Int
64 Pwr Int	74 SUM Int	92 INV SBR

TEXAS INSTRUMENTS INCORPORATED

APPENDIX J

COMPUTER PRINTOUTS AND HAND CALCULATIONS

(Included in Tables 3-16 through 3-26)

REFERENCE 1 DATA

(From Tables 3-3, 3-4, and 3-5)

SPLIN2 PROGRAM - 02/22/82 V1

TEST ID: LA COUNTY SUMMARY TABLE TEST C-369 SCRUBBER INLET

INPUT DATA: PROCESS WEIGHT RATE = 113 TONS PROD. /HR
TOTAL PARTICULATE EMISSION RATE = 352 LB/HR
PARTICLE DENSITY = 2.4 G/CC

MEASURED PARTICLE SIZE DISTRIBUTION

CUT (um)	RAW % < CUT	CUM. % < CUT
10	76.4	76.4
20	6.3	82.7
44	2.8	85.5
74	14.5	100

OUTPUT DATA: TP EMISSION FACTOR = 3.11504 LB/T (1.55752 KG/MT)

CUT (umA)	CUM. % < CUT	EMISSION FACTOR (LB/T)	(KG/MT)
.625	28.6591	.892744	.446372
1	35.2163	1.097	.548502
1.25	38.5441	1.20067	.600333
2.5	49.4708	1.54104	.770518
5	60.3947	1.88755	.943776
10	70.8298	2.20638	1.10319
15	75.9369	2.36547	1.18273
20	79.0119	2.46125	1.23063

END OF TEST SERIES

SPLIN2 PROGRAM - 02/22/82 V1

TEST ID: LA COUNTY SUMMARY TABLE TEST C-369 SCRUBBER OUTLET

INPUT DATA: PROCESS WEIGHT RATE = 113 TONS PROD. /HR
TOTAL PARTICULATE EMISSION RATE = 24.4 LB/HR
PARTICLE DENSITY = 2.4 G/CC

MEASURED PARTICLE SIZE DISTRIBUTION

CUT (um)	RAW % < CUT	CUM. % < CUT
10	79.9	79.9
20	3.8	83.7
44	2	85.7
74	14.3	100

OUTPUT DATA: TP EMISSION FACTOR = .215929 LB/T (.107965 KG/MT)

CUT (umA)	CUM. % < CUT	EMISSION FACTOR (LB/T)	(KG/MT)
.625	46.9872	.101459	.0507295
1	52.4436	.113241	.0566205
1.25	55.0381	.118843	.0594217
2.5	62.9364	.135898	.067949
5	70.2577	.151707	.0758534
10	76.5667	.16533	.082665
15	79.6239	.171931	.0859656
20	81.4592	.175894	.0879471

END OF TEST SERIES

SPLIN2 PROGRAM - 02/22/82 V1

TEST ID: LA COUNTY SUMMARY TABLE TEST C-372A SCRUBBER INLET

INPUT DATA: PROCESS WEIGHT RATE = 158 TONS PROD. /HR
TOTAL PARTICULATE EMISSION RATE = 76 LB/HR
PARTICLE DENSITY = 2.4 G/CC

MEASURED PARTICLE SIZE DISTRIBUTION

CUT (um)	RAW % < CUT	CUM. % < CUT
10	78	78
20	18	96
44	2	98
74	2	100

OUTPUT DATA: TP EMISSION FACTOR = .481013 LB/T (.240506 KG/MT)

CUT (umA)	CUM. % < CUT	EMISSION FACTOR (LB/T)	(KG/MT)
.625	2.91293	.0140115	7.00577E-03
1	5.97526	.0287418	.0143709
1.25	8.16774	.0392879	.0196439
2.5	19.1807	.0922615	.0461307
5	37.7237	.181456	.0907279
10	62.1375	.298889	.149445
15	76.6369	.368633	.184317
20	85.72	.412324	.206162

END OF TEST SERIES

SPLIN2 PROGRAM - 02/22/82 V1

TEST ID: LA COUNTY SUMMARY TABLE TEST C-372A SCRUBBER OUTLET

INPUT DATA: PROCESS WEIGHT RATE = 158 TONS PROD. /HR
TOTAL PARTICULATE EMISSION RATE = 10 LB/HR
PARTICLE DENSITY = 2.4 G/CC

MEASURED PARTICLE SIZE DISTRIBUTION

CUT (um)	RAW % < CUT	CUM. % < CUT
10	83	83
20	5	88
44	1	89
74	11	100

OUTPUT DATA: TP EMISSION FACTOR = .0632911 LB/T (.0316456 KG/MT)

CUT (umA)	CUM. % < CUT	EMISSION FACTOR (LB/T)	(KG/MT)
.625	34.8788	.0220752	.0110376
1	42.0797	.0266327	.0133163
1.25	45.6662	.0289027	.0144513
2.5	57.1342	.0361609	.0180804
5	68.3068	.0432322	.0216161
10	78.0367	.0493903	.0246951
15	82.6004	.0522787	.0261394
20	85.1924	.0539192	.0269596

END OF TEST SERIES

SPLIN2 PROGRAM - 02/22/82 V1

TEST ID: LA COUNTY SUMMARY TABLE TEST C-372B SCRUBBER INLET

INPUT DATA: PROCESS WEIGHT RATE = 142.9 TONS PROD. /HR
TOTAL PARTICULATE EMISSION RATE = 121 LB/HR
PARTICLE DENSITY = 2.4 G/CC

MEASURED PARTICLE SIZE DISTRIBUTION

CUT (um)	RAW % < CUT	CUM. % < CUT
10	91	90.9818
20	9	99.98
44	*.01	99.99
74	*.01	100

OUTPUT DATA: TP EMISSION FACTOR = .846746 LB/T (.423373 KG/MT)

CUT (umA)	CUM. % < CUT	EMISSION FACTOR (LB/T)	(KG/MT)
.625	18.4968	.156621	.0783103
1	26.2785	.222512	.111256
1.25	30.6085	.259177	.129588
2.5	46.3769	.392695	.196347
5	64.3388	.544786	.272393
10	81.7252	.692005	.346003
15	90.2349	.76406	.38203
20	95.0498	.804831	.402415

END OF TEST SERIES

* Model will not accept zero values.

SPLIN2 PROGRAM - 02/22/82 V1

TEST ID: LA COUNTY SUMMARY TABLE TEST C-372B SCRUBBER OUTLET

INPUT DATA: PROCESS WEIGHT RATE = 142.9 TONS PROD. /HR
TOTAL PARTICULATE EMISSION RATE = 19.2 LB/HR
PARTICLE DENSITY = 2.4 G/CC

MEASURED PARTICLE SIZE DISTRIBUTION

CUT (um)	RAW % < CUT	CUM. % < CUT
10	82	82
20	3	85
44	2	87
74	13	100

OUTPUT DATA: TP EMISSION FACTOR = .13436 LB/T (.0671799 KG/MT)

CUT (umA)	CUM. % < CUT	EMISSION FACTOR (LB/T)	(KG/MT)
.625	57.3976	.0771192	.0385596
1	61.6563	.0828412	.0414206
1.25	63.6388	.0855048	.0427524
2.5	69.5435	.0934384	.0467192
5	74.9027	.100639	.0503195
10	79.5144	.106835	.0534176
15	81.7912	.109894	.0549472
20	83.1956	.111781	.0558907

END OF TEST SERIES

SPLIN2 PROGRAM - 02/22/82 V1

TEST ID: LA COUNTY SUMMARY TABLE TEST C-422(1) SCRUBBER OUTLET

INPUT DATA: PROCESS WEIGHT RATE = 198 TONS PROD. /HR
TOTAL PARTICULATE EMISSION RATE = 26.6 LB/HR
PARTICLE DENSITY = 2.4 G/CC

MEASURED PARTICLE SIZE DISTRIBUTION

CUT (um)	RAW % < CUT	CUM. % < CUT
10	73.2	73.2
20	5.1	78.3
44	4.5	82.8
74	17.2	100

OUTPUT DATA: TP EMISSION FACTOR = .134343 LB/T (.0671717 KG/MT)

CUT (umA)	CUM. % < CUT	EMISSION FACTOR (LB/T)	(KG/MT)
.625	42.8196	.0575253	.0287626
1	47.3811	.0636534	.0318267
1.25	49.5776	.0666042	.0333021
2.5	56.4315	.075812	.037906
5	63.1468	.0848335	.0424168
10	69.4663	.0933234	.0466617
15	72.8738	.0979012	.0489506
20	75.126	.100927	.0504634

END OF TEST SERIES

SPLIN2 PROGRAM - 02/22/82 V1

TEST ID: 1960 LOS ANGELES COUNTY TEST#C-426 VENT LINE

INPUT DATA: PROCESS WEIGHT RATE = 182 TONS PROD./HR
TOTAL PARTICULATE EMISSION RATE = 2000 LB/HR
PARTICLE DENSITY = 2.4 G/CC

MEASURED SIZE DISTRIBUTION

CUT(um)	CUM. % < CUT
2	3
5	19.3
10	39.7
15	52.7
20	60.7
30	74
40	81.6
50	85.8
60	88

OUTPUT DATA: TP EMISSION FACTOR = 10.989 LB/T (5.49451 KG/MT)

CUT (umA)	CUM. % < CUT	EMISSION FACTOR (LB/T)	(KG/MT)
.625	9.34642E-03	1.02708E-03	5.13539E-04
1	.0701322	7.70684E-03	3.85342E-03
1.25	.166	.0182418	9.1209E-03
2.5	1.63158	.179295	.0896475
5	8.87455	.975225	.487613
10	25.9907	2.85612	1.42806
15	38.4209	4.22208	2.11104
20	47.7338	5.24548	2.62274

END OF TEST SERIES

SPLIN2 PROGRAM - 02/22/82 V1

TEST ID: 1960 LOS ANGLES COUNTY TEST#C-426 CYCLONE OUTLET

INPUT DATA: PROCESS WEIGHT RATE = 182 TONS PROD./HR
TOTAL PARTICULATE EMISSION RATE = 2620 LB/HR
PARTICLE DENSITY = 2.4 G/CC

* MEASURED SIZE DISTRIBUTION

CUT(um)	CUM. % < CUT
2	1.3
5	5.4
10	10.3
15	14.3
20	17.8
30	25.4
40	33.8
50	44.6
60	51.1

OUTPUT DATA: TP EMISSION FACTOR = 14.3956 LB/T (7.1978 KG/MT)

CUT (umA)	CUM. % < CUT	EMISSION FACTOR (LB/T)	(KG/MT)
.625	.0221413	3.18737E-03	1.59368E-03
1	.0894864	.0128821	6.44105E-03
1.25	.163587	.0235494	.0117747
2.5	.833455	.119981	.0599904
5	2.9282	.421532	.210766
10	6.92055	.996256	.498128
15	9.95612	1.43324	.716622
20	12.6159	1.81613	.908065

END OF TEST SERIES

* Particles > 60 μmS and 3-4 μmS not used as input to model (see Section 3.5.2 of text).

SPLIN2 PROGRAM - 02/22/82 V1

TEST ID: 1960 LOS ANGELES COUNTY TEST#C-426 CYCLONE INLET

INPUT DATA: PROCESS WEIGHT RATE = 182 TONS PROD./HR
TOTAL PARTICULATE EMISSION RATE = 6700 LB/HR
PARTICLE DENSITY = 2.4 G/CC

* MEASURED SIZE DISTRIBUTION

CUT(um)	CUM. % < CUT
2	1.5
5	10.1
10	21.1
15	27.8
20	32.1
30	40.8
40	47.7
50	53.5
60	56.6

OUTPUT DATA: TP EMISSION FACTOR = 36.8132 LB/T (18.4066 KG/MT)

CUT (umA)	CUM. % < CUT	EMISSION FACTOR (LB/T)	EMISSION FACTOR (KG/MT)
.625	4.02547E-03	1.4819E-03	7.40952E-04
1	.03184	.0117213	5.86066E-03
1.25	.07707	.0283719	.014186
2.5	.80332	.295728	.147864
5	4.55854	1.67815	.839073
10	13.7273	5.05344	2.52672
15	20.4088	7.51313	3.75657
20	25.2256	9.28636	4.64318

END OF TEST SERIES

* Particles > 60 μmS and 3-4 μmS not used as input to model (see Section 3.5.2 of text).

SPLIN2 PROGRAM - 02/22/82 V1

TEST ID: 1960 LOS ANGELES COUNTY TEST#C-393 SCRUBBER INLET

INPUT DATA: PROCESS WEIGHT RATE = 92.3 TONS PROD./HR
TOTAL PARTICULATE EMISSION RATE = 4260 LB/HR
PARTICLE DENSITY = 2.4 G/CC

MEASURED SIZE DISTRIBUTION

CUT(um)	CUM. % < CUT
10	13
20	84.1
44	93.7
74	100

OUTPUT DATA: TP EMISSION FACTOR = 46.1538 LB/T (23.0769 KG/MT)

CUT (umA)	CUM. % < CUT	EMISSION FACTOR (LB/T)	(KG/MT)
.625	2.21E-12	1.02E-12	5.1E-13
1	2.16E-09	9.96923E-10	4.98462E-10
1.25	4E-08	1.84615E-08	9.23077E-09
2.5	1.12E-04	5.16923E-05	2.58462E-05
5	.0449	.0207231	.0103615
10	2.8	1.29231	.646154
15	13.9	6.41538	3.20769
20	30.8	14.2154	7.10769

THIS DATA SET WAS FIT TO A LOG-NORMAL SIZE DISTRIBUTION

REFERENCE 3 DATA

(From Tables 3-6 and 3-7)

Conversion of Settling Velocity to Stoke's Diameter for Table 3-4 Using Equation 5:

Calculate Stoke's Diameter for $\rho = 2.4$ gm/cm^3:

Assume: Air at 20°C, 760 mm Hg, & 0% Saturated

$$\eta = 1814\,(10)^{-7} \text{ gm/cm. sec}$$

$$g = 980.665 \text{ cm/sec}^2$$

$$\rho' = 1.2046\,(10)^{-3} \text{ gm/cm}^3$$

For $V_s = 0.2$ cm/sec.

$$D_s = \sqrt{\frac{18\,\eta\,V_s}{(\rho-\rho')\,g}} = \sqrt{\frac{18\,(1814)(10)^{-7}(0.2)}{(2.4-0.0012)(980.665)}} = 5.3\,(10)^{-4}\text{ c}$$

$$= 5.3 \text{ } \mu\text{m S}$$

Remainder of Settling Velocity will increase with a factor of the $\sqrt{2}$ or 1.414.

Settling Velocity (cm/sec.)	Stoke's Diameter (μm S)
0.2	5.3
0.4	7.5
0.8	10.6
1.6	15.0
3.2	21.2
6.4	30.0
12.8	42.4
25.6	60.0

Calc. Stoke's Diameter for $\rho = 2.5$ gm/cm^3:

For $V_s = 0.2$ cm/sec.

$$D_s = \sqrt{\frac{18(1814)(10)^{-7}(0.2)}{(2.5-0.0012)(980.665)}} = 5.2 \text{ } \mu\text{m s}$$

Settling Velocity (cm/sec.)	Stoke's Diameter (μm s)
0.2	5.2
0.4	7.4
0.8	10.4
1.6	14.7
3.2	20.8
6.4	29.4
12.8	41.6
25.6	58.8

Calc. Stoke's Diameter for $\rho = 2.6$ gm/cm^3

For $V_s = 0.2$ cm/sec

$$D_s = \sqrt{\frac{18(1814)(10)^{-7}(0.2)}{(2.6-0.0012)(980.665)}} = 5.1 \text{ } \mu\text{m s}$$

Settling Velocity (cm/sec.)	Stoke's Diameter (μm s)
0.2	5.1
0.4	7.2
0.8	10.2
1.6	14.4
3.2	20.4
6.4	28.3
12.8	40.8
25.6	57.7

Calc. Stoke's Diameter for $\rho = 2.7$ gm/cm^3

For $V_s = 0.2$ cm/sec

$$D_s = \sqrt{\frac{18(1814)(10)^{-7}(0.2)}{(2.7-0.0012)(980.665)}} = 5.0 \text{ } \mu m S$$

Settling Velocity (cm/sec.)	Stoke's Diameter ($\mu m S$)
0.2	5.0
0.4	7.1
0.8	10.0
1.6	14.1
3.2	20.0
6.4	28.3
12.8	40.0
25.6	56.6

Calculate Stoke's Diameter for $\rho = 2.8$ gm/cm^3

For $V_s = 0.2$ cm/sec.

$$D_s = \sqrt{\frac{18(1814)(10)^{-7}(0.2)}{(2.8-0.0012)(980.665)}} = 4.9 \text{ } \mu m S$$

Settling Velocity (cm/sec)	Stoke's Diameter ($\mu m S$)
0.2	4.9
0.4	6.9
0.8	9.8
1.6	13.9
3.2	19.6
6.4	27.7
12.8	39.2
25.6	55.4

Calc. Stoke's Diameter By $\rho = 2.9$ gm/cm^3

For $V_s = 0.2$ cm/sec.

$$D_s = \sqrt{\frac{18(1814)(10)^{-7}(0.2)}{(2.9-0.0012)(980.665)}} = 4.8 \text{ } \mu m S$$

Settling Velocity (cm/sec.)	Stoke's Diameter ($\mu m S$)
0.2	4.8
0.4	6.8
0.8	9.6
1.6	13.6
3.2	19.2
6.4	27.2
12.8	38.4
25.6	54.3

Table ____ . Stokes Diameter vs. Settling Velocity
For Particles of Varying Density

Settling Velocity (cm/sec)[a]	Stokes Diameter for Particles of Varying Density[b]					
	2.4 gm/cm³	2.5 gm/cm³	2.6 gm/cm³	2.7 gm/cm³	2.8 gm/cm³	2.9 gm/cm³
0.2	5.3	5.2	5.1	5.0	4.9	4.8
0.4	7.5	7.4	7.2	7.1	6.9	6.8
0.8	10.6	10.4	10.2	10.0	9.8	9.6
1.6	15.0	14.7	14.4	14.1	13.9	13.6
3.2	21.2	20.8	20.4	20.0	19.6	19.2
6.4	30.0	29.4	28.8	28.3	27.7	27.2
12.8	42.4	41.6	40.8	40.0	39.2	38.4
25.6	60.0	58.8	57.7	56.6	55.4	54.3

b. Calculated from Equation (5) with: $\eta = 1814\,(10)^{-7}$ gm/cm·sec.; $g = 980.665$ cm/sec²; $\rho' = 1.2046\,(10)^{-3}$ gm/cm³; and ρ = to the values shown in each column.

a. Assumes dry air at 20°C & 760 mm Hg.

SPLIN2 PROGRAM - 02/22/82 V1

PROCESS DATA NOT AVAILABLE; EMISSION FACTOR DIRECTLY INPUT
TEST ID: GERMAN STUDY PLANT ID NO. A4 CYCLONE INLET

INPUT DATA: PROCESS WEIGHT RATE = 0 TONS PROD./HR
TOTAL PARTICULATE EMISSION RATE = 0 LB/HR
PARTICLE DENSITY = 2.4 G/CC

MEASURED SIZE DISTRIBUTION

CUT(um)	CUM. % < CUT
5.3	10.5
7.5	16.7
10.6	23.2
15	28.6
21.2	34.3
30	39.7
42.4	46
60	57.1
74	100

OUTPUT DATA: TP EMISSION FACTOR = 18.8 LB/T (9.4 KG/MT)

CUT (umA)	CUM. % < CUT	EMISSION FACTOR (LB/T)	(KG/MT)
.625	5.06462E-03	9.52148E-04	4.76074E-04
1	.0354255	6.65999E-03	3.33E-03
1.25	.0818376	.0153855	7.69273E-03
2.5	.774093	.145529	.0727647
5	4.28616	.805799	.402899
10	13.8925	2.61178	1.30589
15	21.5391	4.04934	2.02467
20	26.2601	4.9369	2.46845

END OF TEST SERIES

SPLIN2 PROGRAM - 02/22/82 V1

PROCESS DATA NOT AVAILABLE; EMISSION FACTOR DIRECTLY INPUT
TEST ID: GERMAN STUDY PLANT ID NO. A4 CYCLONE OUTLET

INPUT DATA: PROCESS WEIGHT RATE = 0 TONS PROD. /HR
TOTAL PARTICULATE EMISSION RATE = 0 LB/HR
PARTICLE DENSITY = 2.6 G/CC

MEASURED PARTICLE SIZE DISTRIBUTION

CUT (um)	RAW % < CUT	CUM. % < CUT
10	23.2	23.2
20	11.1	34.3
40	11.7	46
74	54	100

OUTPUT DATA: TP EMISSION FACTOR = .916 LB/T (.458 KG/MT)

CUT (umA)	CUM. % < CUT	EMISSION FACTOR (LB/T)	(KG/MT)
.625	1.01021	9.2535E-03	4.62675E-03
1	1.81471	.0166227	8.31137E-03
1.25	2.35923	.0216106	.0108053
2.5	4.99792	.0457809	.0228905
5	9.60428	.0879752	.0439876
10	16.7416	.153353	.0766767
15	22.1483	.202878	.101439
20	26.4721	.242485	.121242

END OF TEST SERIES

SPLIN2 PROGRAM - 02/22/82 V1

PROCESS DATA NOT AVAILABLE; EMISSION FACTOR DIRECTLY INPUT
TEST ID: GERMAN STUDY PLANT ID NO. D1 CYCLONE INLET

INPUT DATA: PROCESS WEIGHT RATE = 0 TONS PROD./HR
TOTAL PARTICULATE EMISSION RATE = 0 LB/HR
PARTICLE DENSITY = 2.6 G/CC

MEASURED SIZE DISTRIBUTION

CUT(um)	CUM. % < CUT
5.1	7
7.2	13.1
10.2	18.2
14.4	22.8
20.4	26.7
28.8	28.8
40.8	32
57.7	38.2
74	100

OUTPUT DATA: TP EMISSION FACTOR = 42 LB/T (21 KG/MT)

CUT (umA)	CUM. % < CUT	EMISSION FACTOR (LB/T)	(KG/MT)
.625	4.90417E-06	2.05975E-06	1.02988E-06
1	2.26465E-04	9.51154E-05	4.75577E-05
1.25	1.14969E-03	4.8287E-04	2.41435E-04
2.5	.0803031	.0337273	.0168637
5	1.67117	.70189	.350945
10	10.362	4.35205	2.17602
15	16.8908	7.09415	3.54708
20	20.8641	8.76291	4.38146

END OF TEST SERIES

SPLIN2 PROGRAM - 02/22/82 V1

PROCESS DATA NOT AVAILABLE; EMISSION FACTOR DIRECTLY INPUT
TEST ID: GERMAN STUDY PLANT ID NO. 01 CYCLONE OUTLET

INPUT DATA: PROCESS WEIGHT RATE = 0 TONS PROD. /HR
TOTAL PARTICULATE EMISSION RATE = 0 LB/HR
PARTICLE DENSITY = 2.6 G/CC

MEASURED PARTICLE SIZE DISTRIBUTION

CUT (um)	RAW % < CUT	CUM. % < CUT
10	18.2	18.2
20	8.5	26.7
40	5.3	32
74	68	100

OUTPUT DATA: TP EMISSION FACTOR = 5.24 LB/T (2.62 KG/MT)

CUT (umA)	CUM. % < CUT	EMISSION FACTOR (LB/T)	(KG/MT)
.625	.203426	.0106595	5.32977E-03
1	.512888	.0268753	.0134377
1.25	.770132	.0403549	.0201775
2.5	2.3819	.124811	.0624057
5	6.01839	.315364	.157682
10	12.4233	.650982	.325491
15	17.2845	.905708	.452854
20	20.9505	1.09781	.548904

END OF TEST SERIES

SPLIN2 PROGRAM - 02/22/82 V1

PROCESS DATA NOT AVAILABLE; EMISSION FACTOR DIRECTLY INPUT
TEST ID: GERMAN STUDY PLANT ID NO. H2 CYCLONE INLET

INPUT DATA: PROCESS WEIGHT RATE = 0 TONS PROD./HR
TOTAL PARTICULATE EMISSION RATE = 0 LB/HR
PARTICLE DENSITY = 2.6 G/CC

MEASURED SIZE DISTRIBUTION

CUT(um)	CUM. % < CUT
5.1	8.7
7.2	17
10.2	23.4
14.4	27.6
20.4	33.4
28.8	36.2
40.8	45.9
57.7	59.1
74	100

OUTPUT DATA: TP EMISSION FACTOR = 24.6 LB/T (12.3 KG/MT)

CUT (umA)	CUM. % < CUT	EMISSION FACTOR (LB/T)	EMISSION FACTOR (KG/MT)
.625	8.47661E-07	2.08525E-07	1.04262E-07
1	6.96892E-05	1.71435E-05	8.57177E-06
1.25	4.49736E-04	1.10635E-04	5.53175E-05
2.5	.0575943	.0141682	7.08409E-03
5	1.78027	.437947	.218974
10	13.2826	3.26751	1.63376
15	21.8806	5.38262	2.69131
20	25.7017	6.32261	3.16131

END OF TEST SERIES

SPLIN2 PROGRAM - 02/22/82 V1

PROCESS DATA NOT AVAILABLE; EMISSION FACTOR DIRECTLY INPUT
TEST ID: GERMAN STUDY PLANT ID NO. H2 CYCLONE OUTLET

INPUT DATA: PROCESS WEIGHT RATE = 0 TONS PROD. /HR
TOTAL PARTICULATE EMISSION RATE = 0 LB/HR
PARTICLE DENSITY = 2.6 G/CC

MEASURED PARTICLE SIZE DISTRIBUTION

CUT (um)	RAW % < CUT	CUM. % < CUT
10	23.4	23.4
20	10	33.4
40	12.5	45.9
74	54.1	100

OUTPUT DATA: TP EMISSION FACTOR = 2.06 LB/T (1.03 KG/MT)

CUT (umA)	CUM. % < CUT	EMISSION FACTOR (LB/T)	(KG/MT)
.625	2.66049	.0548061	.0274031
1	3.83612	.0790242	.0395121
1.25	4.53626	.093447	.0467235
2.5	7.4468	.153404	.0767021
5	11.77	.242462	.121231
10	17.911	.368967	.184483
15	22.4984	.463467	.231733
20	26.2421	.540587	.270294

END OF TEST SERIES

SPLIN2 PROGRAM - 02/22/82 V1

PROCESS DATA NOT AVAILABLE; EMISSION FACTOR DIRECTLY INPUT
TEST ID: GERMAN STUDY PLANT ID NO. I2 CYCLONE INLET

INPUT DATA: PROCESS WEIGHT RATE = 0 TONS PROD./HR
TOTAL PARTICULATE EMISSION RATE = 0 LB/HR
PARTICLE DENSITY = 2.9 G/CC

MEASURED SIZE DISTRIBUTION

CUT(um)	CUM. % < CUT
4.8	10.8
6.8	14
9.6	17.2
13.6	25.1
19.2	34.5
27.2	38.5
38.4	47.2
54.3	64.1
74	100

OUTPUT DATA: TP EMISSION FACTOR = 42.2 LB/T (21.1 KG/MT)

CUT (umA)	CUM. % < CUT	EMISSION FACTOR (LB/T)	(KG/MT)
.625	.319802	.134956	.0674782
1	.751574	.317164	.158582
1.25	1.09093	.460374	.230187
2.5	3.03057	1.2789	.639451
5	6.85584	2.89316	1.44658
10	12.6301	5.3299	2.66495
15	16.1233	6.80402	3.40201
20	21.4591	9.05573	4.52786

END OF TEST SERIES

SPLIN2 PROGRAM - 02/22/82 V1

PROCESS DATA NOT AVAILABLE; EMISSION FACTOR DIRECTLY INPUT
TEST ID: GERMAN STUDY PLANT ID NO. I2 CYCLONE OUTLET

INPUT DATA: PROCESS WEIGHT RATE = 0 TONS PROD. /HR
TOTAL PARTICULATE EMISSION RATE = 0 LB/HR
PARTICLE DENSITY = 2.6 G/CC

MEASURED PARTICLE SIZE DISTRIBUTION

CUT (um)	RAW % < CUT	CUM. % < CUT
10	17.2	17.2
20	17.3	34.5
40	12.7	47.2
74	52.8	100

OUTPUT DATA: TP EMISSION FACTOR = 1.12 LB/T (.56 KG/MT)

CUT (umA)	CUM. % < CUT	EMISSION FACTOR (LB/T)	(KG/MT)
.625	3.99466E-03	4.47402E-05	2.23701E-05
1	.0225395	2.52442E-04	1.26221E-04
1.25	.0481914	5.39744E-04	2.69872E-04
2.5	.396545	4.4413E-03	2.22065E-03
5	2.2256	.0249268	.0124634
10	8.51994	.0954234	.0477117
15	15.6471	.175247	.0876236
20	22.2464	.249159	.12458

END OF TEST SERIES

SPLIN2 PROGRAM - 02/22/82 V1

PROCESS DATA NOT AVAILABLE; EMISSION FACTOR DIRECTLY INPUT
TEST ID: GERMAN STUDY PLANT ID NO. I3 CYCLONE INLET

INPUT DATA: PROCESS WEIGHT RATE = 0 TONS PROD./HR
TOTAL PARTICULATE EMISSION RATE = 0 LB/HR
PARTICLE DENSITY = 2.7 G/CC

MEASURED SIZE DISTRIBUTION

CUT(um)	CUM. % < CUT
5	13.7
7.1	29.1
10	40.9
14.1	49.2
20	58.1
28.3	64.7
40	70.2
56.6	80.9
74	100

OUTPUT DATA: TP EMISSION FACTOR = 29.4 LB/T (14.7 KG/MT)

CUT (umA)	CUM. % < CUT	EMISSION FACTOR (LB/T)	(KG/MT)
.625	1.90208E-07	5.5921E-08	2.79605E-08
1	2.68464E-05	7.89284E-06	3.94642E-06
1.25	2.17566E-04	6.39644E-05	3.19822E-05
2.5	.0502156	.0147634	7.3817E-03
5	2.33869	.687574	.343787
10	21.9781	6.46156	3.23078
15	38.0358	11.1825	5.59126
20	45.6821	13.4306	6.71528

END OF TEST SERIES

SPLIN2 PROGRAM - 02/22/82 V1

PROCESS DATA NOT AVAILABLE; EMISSION FACTOR DIRECTLY INPUT
TEST ID: GERMAN STUDY PLANT ID NO. I3 CYCLONE OUTLET

INPUT DATA: PROCESS WEIGHT RATE = 0 TONS PROD. /HR
TOTAL PARTICULATE EMISSION RATE = 0 LB/HR
PARTICLE DENSITY = 2.6 G/CC

MEASURED PARTICLE SIZE DISTRIBUTION

CUT (um)	RAW % < CUT	CUM. % < CUT
10	40.9	40.9
20	17.2	58.1
40	12.1	70.2
74	29.8	100

OUTPUT DATA: TP EMISSION FACTOR = 2.8 LB/T (1.4 KG/MT)

CUT (umA)	CUM. % < CUT	EMISSION FACTOR (LB/T)	(KG/MT)
.625	.910363	.0254902	.0127451
1	1.9668	.0550703	.0275352
1.25	2.76234	.0773456	.0386728
2.5	7.12934	.199622	.0998108
5	15.6506	.438218	.219109
10	29.2229	.818241	.409121
15	39.0639	1.09379	.546895
20	46.4114	1.29952	.64976

END OF TEST SERIES

SPLIN2 PROGRAM - 02/22/82 V1

PROCESS DATA NOT AVAILABLE; EMISSION FACTOR DIRECTLY INPUT
TEST ID: GERMAN STUDY PLANT ID NO. 02 CYCLONE INLET

INPUT DATA: PROCESS WEIGHT RATE = 0 TONS PROD./HR
TOTAL PARTICULATE EMISSION RATE = 0 LB/HR
PARTICLE DENSITY = 2.9 G/CC

MEASURED SIZE DISTRIBUTION

CUT(um)	CUM. % < CUT
4.8	15.1
6.8	25
9.6	41.1
13.3	58.1
19.2	65.4
27.2	67
38.4	69.1
54.3	73.3
74	100

OUTPUT DATA: TP EMISSION FACTOR = 37.6 LB/T (18.8 KG/MT)

CUT (umA)	CUM. % < CUT	EMISSION FACTOR (LB/T)	EMISSION FACTOR (KG/MT)
.625	.34275	.128874	.064437
1	.690512	.259632	.129816
1.25	.961659	.361584	.180792
2.5	2.67615	1.00623	.503117
5	7.38665	2.77738	1.38869
10	20.2223	7.60359	3.80179
15	36.7108	13.8033	6.90163
20	52.2057	19.6293	9.81467

END OF TEST SERIES

SPLIN2 PROGRAM - 02/22/82 V1

PROCESS DATA NOT AVAILABLE; EMISSION FACTOR DIRECTLY INPUT
TEST ID: GERMAN STUDY PLANT ID NO. 02 CYCLONE OUTLET

INPUT DATA: PROCESS WEIGHT RATE = 0 TONS PROD. /HR
TOTAL PARTICULATE EMISSION RATE = 0 LB/HR
PARTICLE DENSITY = 2.6 G/CC

MEASURED PARTICLE SIZE DISTRIBUTION

CUT (um)	RAW % < CUT	CUM. % < CUT
10	41.1	41.1
20	24.3	65.4
40	3.7	69.1
74	30.9	100

OUTPUT DATA: TP EMISSION FACTOR = 7.54 LB/T (3.77 KG/MT)

CUT (umA)	CUM. % < CUT	EMISSION FACTOR (LB/T)	(KG/MT)
.625	.0197552	1.48954E-03	7.44771E-04
1	.104072	7.84705E-03	3.92352E-03
1.25	.214452	.0161696	8.08482E-03
2.5	1.54576	.11655	.0582752
5	7.39811	.557818	.278909
10	23.5107	1.7727	.886352
15	38.2438	2.88359	1.44179
20	49.6107	3.74064	1.87032

END OF TEST SERIES

SPLIN2 PROGRAM - 02/22/82 V1

PROCESS DATA NOT AVAILABLE; EMISSION FACTOR DIRECTLY INPUT
TEST ID: GERMAN STUDY PLANT ID NO. C1 CYCLONE INLET

INPUT DATA: PROCESS WEIGHT RATE = 0 TONS PROD./HR
TOTAL PARTICULATE EMISSION RATE = 0 LB/HR
PARTICLE DENSITY = 2.5 G/CC

MEASURED SIZE DISTRIBUTION

CUT(um)	CUM. % < CUT
5.2	6.9
7.4	13.8
10.4	22
14.7	29.6
20.8	37.2
29.4	45.9
41.6	54.7
58.8	74.1
74	100

OUTPUT DATA: TP EMISSION FACTOR = 72.6 LB/T (36.3 KG/MT)

CUT (umA)	CUM. % < CUT	EMISSION FACTOR (LB/T)	(KG/MT)
.625	6.75364E-05	4.90314E-05	2.45157E-05
1	1.29393E-03	9.39393E-04	4.69696E-04
1.25	4.60419E-03	3.34265E-03	1.67132E-03
2.5	.137719	.0999837	.0499918
5	1.8074	1.31217	.656086
10	10.4073	7.55571	3.77785
15	19.7365	14.3287	7.16434
20	26.2973	19.0918	9.54591

END OF TEST SERIES

SPLIN2 PROGRAM - 02/22/82 V1

PROCESS DATA NOT AVAILABLE; EMISSION FACTOR DIRECTLY INPUT
TEST ID: GERMAN STUDY PLANT ID NO. C1 CYCLONE OUTLET

INPUT DATA: PROCESS WEIGHT RATE = 0 TONS PROD. /HR
TOTAL PARTICULATE EMISSION RATE = 0 LB/HR
PARTICLE DENSITY = 2.6 G/CC

MEASURED PARTICLE SIZE DISTRIBUTION

CUT (um)	RAW % < CUT	CUM. % < CUT
10	22	22
20	15.2	37.2
40	17.5	54.7
74	45.3	100

OUTPUT DATA: TP EMISSION FACTOR = 3.54 LB/T (1.77 KG/MT)

CUT (umA)	CUM. % < CUT	EMISSION FACTOR (LB/T)	(KG/MT)
.625	.290619	.0102879	5.14396E-03
1	.656995	.0232576	.0116288
1.25	.946186	.033495	.0167475
2.5	2.67886	.0948318	.0474159
5	6.59549	.23348	.11674
10	14.121	.499884	.249942
15	20.6603	.731376	.365688
20	26.291	.930703	.465351

END OF TEST SERIES

SPLIN2 PROGRAM - 02/22/82 V1

PROCESS DATA NOT AVAILABLE; EMISSION FACTOR DIRECTLY INPUT
TEST ID: GERMAN STUDY PLANT ID NO. C2 CYCLONE INLET

INPUT DATA: PROCESS WEIGHT RATE = 0 TONS PROD./HR
TOTAL PARTICULATE EMISSION RATE = 0 LB/HR
PARTICLE DENSITY = 2.5 G/CC

MEASURED SIZE DISTRIBUTION

CUT(um)	CUM. % < CUT
5.2	7.6
7.4	16.9
10.4	24.9
14.7	31.7
20.8	37.4
29.4	42.6
41.6	50.9
58.8	58.9
74	100

OUTPUT DATA: TP EMISSION FACTOR = 72.2 LB/T (36.1 KG/MT)

CUT (umA)	CUM. % < CUT	EMISSION FACTOR (LB/T)	(KG/MT)
.625	1.04337E-07	7.53311E-08	3.76655E-08
1	1.41687E-05	1.02298E-05	5.11489E-06
1.25	1.13451E-04	8.19113E-05	4.09557E-05
2.5	.0258845	.0186886	9.34432E-03
5	1.23919	.894697	.447348
10	12.4481	8.98751	4.49376
15	22.8192	16.4754	8.23772
20	28.8498	20.8295	10.4148

END OF TEST SERIES

SPLIN2 PROGRAM - 02/22/82 V1

PROCESS DATA NOT AVAILABLE; EMISSION FACTOR DIRECTLY INPUT
TEST ID: GERMAN STUDY PLANT ID NO. C2 CYCLONE OUTLET

INPUT DATA: PROCESS WEIGHT RATE = 0 TONS PROD. /HR
TOTAL PARTICULATE EMISSION RATE = 0 LB/HR
PARTICLE DENSITY = 2.6 G/CC

MEASURED PARTICLE SIZE DISTRIBUTION

CUT (um)	RAW % < CUT	CUM. % < CUT
10	24.9	25.8836
20	12.5	38.8773
40	13.5	52.9106
74	45.3	100

OUTPUT DATA: TP EMISSION FACTOR = 4.1 LB/T (2.05 KG/MT)

CUT (umA)	CUM. % < CUT	EMISSION FACTOR (LB/T)	(KG/MT)
.625	1.03112	.0422761	.021138
1	1.8791	.0770431	.0385216
1.25	2.45924	.100829	.0504144
2.5	5.31454	.217896	.108948
5	10.4065	.426667	.213334
10	18.4638	.757015	.378507
15	24.6679	1.01138	.505692
20	29.6832	1.21701	.608506

END OF TEST SERIES

SPLIN2 PROGRAM - 02/22/82 V1

PROCESS DATA NOT AVAILABLE; EMISSION FACTOR DIRECTLY INPUT
TEST ID: GERMAN STUDY PLANT ID NO. B3 CYCLONE INLET

INPUT DATA: PROCESS WEIGHT RATE = 0 TONS PROD./HR
TOTAL PARTICULATE EMISSION RATE = 0 LB/HR
PARTICLE DENSITY = 2.6 G/CC

MEASURED SIZE DISTRIBUTION

CUT(um)	CUM. % < CUT
5.1	4.2
7.2	7.7
10.2	12.5
14.4	18.3
20.4	25.4
28.8	32.7
40.8	41.4
57.7	56.7
74	100

OUTPUT DATA: TP EMISSION FACTOR = 93.4 LB/T (46.7 KG/MT)

CUT (umA)	CUM. % < CUT	EMISSION FACTOR (LB/T)	(KG/MT)
.625	8.4312E-04	7.87474E-04	3.93737E-04
1	6.72639E-03	6.28245E-03	3.14123E-03
1.25	.0166124	.015516	7.75801E-03
2.5	.196869	.183875	.0919377
5	1.4032	1.31059	.655294
10	6.01537	5.61835	2.80918
15	11.1082	10.3751	5.18753
20	15.6364	14.6044	7.30218

END OF TEST SERIES

SPLIN2 PROGRAM - 02/22/82 V1

PROCESS DATA NOT AVAILABLE; EMISSION FACTOR DIRECTLY INPUT
TEST ID: GERMAN STUDY PLANT ID NO. B3 CYCLONE OUTLET

INPUT DATA: PROCESS WEIGHT RATE = 0 TONS PROD. /HR
TOTAL PARTICULATE EMISSION RATE = 0 LB/HR
PARTICLE DENSITY = 2.6 G/CC

MEASURED PARTICLE SIZE DISTRIBUTION

CUT (um)	RAW % < CUT	CUM. % < CUT
10	12.5	12.5
20	12.9	25.4
40	16	41.4
74	58.6	100

OUTPUT DATA: TP EMISSION FACTOR = 2.44 LB/T (1.22 KG/MT)

CUT (umA)	CUM. % < CUT	EMISSION FACTOR (LB/T)	(KG/MT)
.625	.0237498	5.79495E-04	2.89748E-04
1	.0793193	1.93539E-03	9.67696E-04
1.25	.13571	3.31132E-03	1.65566E-03
2.5	.622023	.0151774	7.58868E-03
5	2.28689	.0558001	.0279
10	6.74413	.164557	.0822784
15	11.4626	.279687	.139843
20	15.9533	.389261	.19463

END OF TEST SERIES

SPLIN2 PROGRAM - 02/22/82 V1

PROCESS DATA NOT AVAILABLE; EMISSION FACTOR DIRECTLY INPUT
TEST ID: GERMAN STUDY PLANT ID NO. D4 CYCLONE INLET

INPUT DATA: PROCESS WEIGHT RATE = 0 TONS PROD./HR
TOTAL PARTICULATE EMISSION RATE = 0 LB/HR
PARTICLE DENSITY = 2.8 G/CC

MEASURED SIZE DISTRIBUTION

CUT(um)	CUM. % < CUT
4.9	15.9
6.9	26.8
9.8	41.5
13.9	53.8
19.6	61.5
27.7	67.6
39.2	72
55.4	80.6
74	100

OUTPUT DATA: TP EMISSION FACTOR = 149.2 LB/T (74.6 KG/MT)

CUT (umA)	CUM. % < CUT	EMISSION FACTOR (LB/T)	EMISSION FACTOR (KG/MT)
.625	.015282	.0228008	.0114004
1	.0809016	.120705	.0603526
1.25	.167706	.250218	.125109
2.5	1.25014	1.86521	.932606
5	6.33009	9.4445	4.72225
10	21.7722	32.4841	16.2421
15	37.7312	56.2949	28.1474
20	48.886	72.9378	36.4689

END OF TEST SERIES

SPLIN2 PROGRAM - 02/22/82 V1

PROCESS DATA NOT AVAILABLE; EMISSION FACTOR DIRECTLY INPUT
TEST ID: GERMAN STUDY PLANT ID NO. D4 CYCLONE OUTLET

INPUT DATA: PROCESS WEIGHT RATE = 0 TONS PROD. /HR
TOTAL PARTICULATE EMISSION RATE = 0 LB/HR
PARTICLE DENSITY = 2.6 G/CC

MEASURED PARTICLE SIZE DISTRIBUTION

CUT (um)	RAW % < CUT	CUM. % < CUT
10	41.5	41.5
20	20	61.5
40	10.5	72
74	28	100

OUTPUT DATA: TP EMISSION FACTOR = 20.8 LB/T (10.4 KG/MT)

CUT (umA)	CUM. % < CUT	EMISSION FACTOR (LB/T)	(KG/MT)
.625	.282783	.0588189	.0294094
1	.80161	.166735	.0833675
1.25	1.26568	.263261	.131631
2.5	4.47531	.930864	.465432
5	12.5012	2.60025	1.30012
10	27.5872	5.73815	2.86907
15	39.295	8.17336	4.08668
20	48.0945	10.0036	5.00182

END OF TEST SERIES

SPLIN2 PROGRAM - 02/22/82 V1

PROCESS DATA NOT AVAILABLE; EMISSION FACTOR DIRECTLY INPUT
TEST ID: GERMAN STUDY PLANT ID NO. F3 CYCLONE INLET

INPUT DATA: PROCESS WEIGHT RATE = 0 TONS PROD./HR
TOTAL PARTICULATE EMISSION RATE = 0 LB/HR
PARTICLE DENSITY = 2.4 G/CC

MEASURED SIZE DISTRIBUTION

CUT(um)	CUM. % < CUT
5.3	11
7.5	19.8
10.6	27.7
15	35.5
21.2	43.2
30	48.9
42.4	57.6
60	66.9
74	100

OUTPUT DATA: TP EMISSION FACTOR = 73.8 LB/T (36.9 KG/MT)

CUT (umA)	CUM. % < CUT	EMISSION FACTOR (LB/T)	(KG/MT)
.625	5.50136E-05	4.06E-05	2.03E-05
1	1.43158E-03	1.05651E-03	5.28253E-04
1.25	5.72483E-03	4.22492E-03	2.11246E-03
2.5	.218811	.161483	.0807414
5	3.0718	2.26699	1.13349
10	15.8391	11.6893	5.84463
15	25.6354	18.9189	9.45946
20	32.1089	23.6963	11.8482

END OF TEST SERIES

SPLIN2 PROGRAM - 02/22/82 V1

PROCESS DATA NOT AVAILABLE; EMISSION FACTOR DIRECTLY INPUT
TEST ID: GERMAN STUDY PLANT ID NO. F3 CYCLONE OUTLET

INPUT DATA: PROCESS WEIGHT RATE = 0 TONS PROD. /HR
TOTAL PARTICULATE EMISSION RATE = 0 LB/HR
PARTICLE DENSITY = 2.6 G/CC

MEASURED PARTICLE SIZE DISTRIBUTION

CUT (um)	RAW % < CUT	CUM. % < CUT
10	27.7	27.7
20	15.5	43.2
40	14.4	57.6
74	42.4	100

OUTPUT DATA: TP EMISSION FACTOR = 4.7 LB/T (2.35 KG/MT)

CUT (umA)	CUM. % < CUT	EMISSION FACTOR (LB/T)	(KG/MT)
.625	.426108	.0200271	.0100135
1	.964358	.0453248	.0226624
1.25	1.38577	.0651313	.0325657
2.5	3.85301	.181092	.0905458
5	9.15894	.43047	.215235
10	18.6134	.874832	.437416
15	26.2079	1.23177	.615885
20	32.3403	1.52	.759998

END OF TEST SERIES

SPLIN2 PROGRAM - 02/22/82 V1

PROCESS DATA NOT AVAILABLE; EMISSION FACTOR DIRECTLY INPUT
TEST ID: GERMAN STUDY PLANT ID NO. G2 CYCLONE INLET

INPUT DATA: PROCESS WEIGHT RATE = 0 TONS PROD./HR
TOTAL PARTICULATE EMISSION RATE = 0 LB/HR
PARTICLE DENSITY = 2.5 G/CC

MEASURED SIZE DISTRIBUTION

CUT(um)	CUM. % < CUT
5.2	8.3
7.4	20.1
10.4	37
14.7	50.2
20.8	59.6
29.4	66.7
41.6	72.1
58.8	82.5
74	100

OUTPUT DATA: TP EMISSION FACTOR = 60.8 LB/T (30.4 KG/MT)

CUT (umA)	CUM. % < CUT	EMISSION FACTOR (LB/T)	(KG/MT)
.625	5.4587E-06	3.31889E-06	1.65945E-06
1	2.03038E-04	1.23447E-04	6.17236E-05
1.25	9.63863E-04	5.86029E-04	2.93015E-04
2.5	.0632614	.0384629	.0192315
5	1.54333	.938345	.469173
10	13.9952	8.50906	4.25453
15	32.3182	19.6494	9.82472
20	44.8617	27.2759	13.6379

END OF TEST SERIES

SPLIN2 PROGRAM - 02/22/82 V1

PROCESS DATA NOT AVAILABLE; EMISSION FACTOR DIRECTLY INPUT
TEST ID: GERMAN STUDY PLANT ID NO. G2 CYCLONE OUTLET

INPUT DATA: PROCESS WEIGHT RATE = 0 TONS PROD. /HR
TOTAL PARTICULATE EMISSION RATE = 0 LB/HR
PARTICLE DENSITY = 2.6 G/CC

MEASURED PARTICLE SIZE DISTRIBUTION

CUT (um)	RAW % < CUT	CUM. % < CUT
10	37	37
20	22.6	59.6
40	12.5	72.1
74	27.9	100

OUTPUT DATA: TP EMISSION FACTOR = 6.16 LB/T (3.08 KG/MT)

CUT (umA)	CUM. % < CUT	EMISSION FACTOR (LB/T)	(KG/MT)
.625	.0868022	5.34702E-03	2.67351E-03
1	.307537	.0189443	9.47215E-03
1.25	.535432	.0329826	.0164913
2.5	2.48041	.152793	.0763967
5	8.62957	.531582	.265791
10	22.5476	1.38893	.694466
15	34.6296	2.13318	1.06659
20	44.2443	2.72545	1.36273

END OF TEST SERIES

SPLIN2 PROGRAM - 02/22/82 V1

PROCESS DATA NOT AVAILABLE; EMISSION FACTOR DIRECTLY INPUT
TEST ID: GERMAN STUDY PLANT ID NO. G1 CYCLONE INLET

INPUT DATA: PROCESS WEIGHT RATE = 0 TONS PROD./HR
TOTAL PARTICULATE EMISSION RATE = 0 LB/HR
PARTICLE DENSITY = 2.5 G/CC

MEASURED SIZE DISTRIBUTION

CUT(um)	CUM. % < CUT
5.2	5.9
7.4	16.5
10.4	29.1
14.7	35.1
20.8	43.8
29.4	53.9
41.6	66
58.8	81.9
74	100

OUTPUT DATA: TP EMISSION FACTOR = 55.8 LB/T (27.9 KG/MT)

CUT (umA)	CUM. % < CUT	EMISSION FACTOR (LB/T)	EMISSION FACTOR (KG/MT)
.625	4.0479E-09	2.25873E-09	1.12936E-09
1	1.12921E-06	6.30101E-07	3.1505E-07
1.25	1.23859E-05	6.91134E-06	3.45567E-06
2.5	6.72062E-03	3.75011E-03	1.87505E-03
5	.646657	.360834	.180417
10	11.0338	6.15684	3.07842
15	25.9301	14.469	7.2345
20	32.4878	18.1282	9.06411

END OF TEST SERIES

SPLIN2 PROGRAM - 02/22/82 V1

PROCESS DATA NOT AVAILABLE; EMISSION FACTOR DIRECTLY INPUT
TEST ID: GERMAN STUDY PLANT ID NO. G1 CYCLONE OUTLET

INPUT DATA: PROCESS WEIGHT RATE = 0 TONS PROD. /HR
TOTAL PARTICULATE EMISSION RATE = 0 LB/HR
PARTICLE DENSITY = 2.6 G/CC

MEASURED PARTICLE SIZE DISTRIBUTION

CUT (um)	RAW % < CUT	CUM. % < CUT
10	29.1	29.1
20	14.7	43.8
40	22.2	66
74	34	100

OUTPUT DATA: TP EMISSION FACTOR = 6.4 LB/T (3.2 KG/MT)

CUT (umA)	CUM. % < CUT	EMISSION FACTOR (LB/T)	(KG/MT)
.625	4.34206	.277892	.138946
1	5.70821	.365325	.182663
1.25	6.50104	.416067	.208033
2.5	9.74449	.623648	.311824
5	14.6226	.935847	.467923
10	21.9674	1.40592	.702958
15	27.8869	1.78476	.892382
20	33.0387	2.11448	1.05724

END OF TEST SERIES

SPLIN2 PROGRAM - 02/22/82 V1

PROCESS DATA NOT AVAILABLE; EMISSION FACTOR DIRECTLY INPUT
TEST ID: GERMAN STUDY PLANT ID NO. B1 CYCLONE INLET

INPUT DATA: PROCESS WEIGHT RATE = 0 TONS PROD./HR
TOTAL PARTICULATE EMISSION RATE = 0 LB/HR
PARTICLE DENSITY = 2.5 G/CC

MEASURED SIZE DISTRIBUTION

CUT(um)	CUM. % < CUT
5.2	3.6
7.4	5.1
10.4	7
14.7	8.9
20.8	10.9
29.4	12.8
41.6	16.3
58.8	23.7
74	100

OUTPUT DATA: TP EMISSION FACTOR = 31.8 LB/T (15.9 KG/MT)

CUT (umA)	CUM. % < CUT	EMISSION FACTOR (LB/T)	(KG/MT)
.625	.152491	.0484921	.024246
1	.294359	.0936062	.0468031
1.25	.397183	.126304	.0631522
2.5	.956288	.3041	.15205
5	2.12832	.676805	.338402
10	4.37859	1.39239	.696196
15	6.47235	2.05821	1.0291
20	8.06365	2.56424	1.28212

END OF TEST SERIES

SPLIN2 PROGRAM - 02/22/82 V1

PROCESS DATA NOT AVAILABLE; EMISSION FACTOR DIRECTLY INPUT
TEST ID: GERMAN STUDY PLANT ID NO. B1 CYCLONE OUTLET

INPUT DATA: PROCESS WEIGHT RATE = 0 TONS PROD. /HR
TOTAL PARTICULATE EMISSION RATE = 0 LB/HR
PARTICLE DENSITY = 2.6 G/CC

MEASURED PARTICLE SIZE DISTRIBUTION

CUT (um)	RAW % < CUT	CUM. % < CUT
10	7	7
20	3.9	10.9
40	5.4	16.3
74	83.7	100

OUTPUT DATA: TP EMISSION FACTOR = .898 LB/T (.449 KG/MT)

CUT (umA)	CUM. % < CUT	EMISSION FACTOR (LB/T)	(KG/MT)
.625	.51156	4.59381E-03	2.29691E-03
1	.789009	7.08531E-03	3.54265E-03
1.25	.962941	8.64721E-03	4.3236E-03
2.5	1.74075	.0156319	7.81595E-03
5	3.02207	.0271382	.0135691
10	5.03858	.0452464	.0226232
15	6.6685	.0598831	.0299416
20	8.0676	.0724471	.0362235

END OF TEST SERIES

SPLIN2 PROGRAM - 02/22/82 V1

PROCESS DATA NOT AVAILABLE; EMISSION FACTOR DIRECTLY INPUT
TEST ID: GERMAN STUDY PLANT ID NO. F2 CYCLONE INLET

INPUT DATA: PROCESS WEIGHT RATE = 0 TONS PROD./HR
TOTAL PARTICULATE EMISSION RATE = 0 LB/HR
PARTICLE DENSITY = 2.5 G/CC

MEASURED SIZE DISTRIBUTION

CUT(um)	CUM. % < CUT
5.2	16.5
7.4	24
10.4	32.5
14.7	41.5
20.8	45.6
29.4	48.5
41.6	53
58.8	60.4
74	100

OUTPUT DATA: TP EMISSION FACTOR = 29.2 LB/T (14.6 KG/MT)

CUT (umA)	CUM. % < CUT	EMISSION FACTOR (LB/T)	EMISSION FACTOR (KG/MT)
.625	.165785	.0484093	.0242046
1	.48994	.143063	.0715313
1.25	.78883	.230338	.115169
2.5	2.96063	.864505	.432252
5	8.76495	2.55937	1.27968
10	20.4681	5.9767	2.98835
15	30.1277	8.79728	4.39864
20	37.9535	11.0824	5.54121

END OF TEST SERIES

SPLIN2 PROGRAM - 02/22/82 V1

PROCESS DATA NOT AVAILABLE; EMISSION FACTOR DIRECTLY INPUT
TEST ID: GERMAN STUDY PLANT ID NO. F2 CYCLONE OUTLET

INPUT DATA: PROCESS WEIGHT RATE = 0 TONS PROD. /HR
TOTAL PARTICULATE EMISSION RATE = 0 LB/HR
PARTICLE DENSITY = 2.6 G/CC

MEASURED PARTICLE SIZE DISTRIBUTION

CUT (um)	RAW % < CUT	CUM. % < CUT
10	32.5	32.5
20	13.1	45.6
40	7.4	53
74	47	100

OUTPUT DATA: TP EMISSION FACTOR = 2.28 LB/T (1.14 KG/MT)

CUT (umA)	CUM. % < CUT	EMISSION FACTOR (LB/T)	(KG/MT)
.625	.538796	.0122846	6.14228E-03
1	1.25917	.0287091	.0143545
1.25	1.82789	.041676	.020838
2.5	5.13696	.117123	.0585613
5	11.9589	.272662	.136331
10	23.0623	.525821	.262911
15	31.0338	.707572	.353786
20	36.8422	.840002	.420001

END OF TEST SERIES

REFERENCE 8 DATA

(From Tables 3-8 and 3-9)

SPLIN2 PROGRAM - 02/22/82 V1

TEST ID: SLOAN 1971 WASHER INLET

INPUT DATA: PROCESS WEIGHT RATE = 225 TONS PROD. /HR
TOTAL PARTICULATE EMISSION RATE = 2135 LB/HR
PARTICLE DENSITY = 1 G/CC

MEASURED PARTICLE SIZE DISTRIBUTION

CUT (um)	RAW % < CUT	CUM. % < CUT
.3	.7	.703518
1	2.3	3.01508
2	9.5	12.5628
3.3	12.2	24.8241
5.5	13.3	38.191
9.2	14.8	53.0653
30	19	72.1608
120	27.7	100

OUTPUT DATA: TP EMISSION FACTOR = 9.48889 LB/T (4.74444 KG/MT)

CUT (umA)	CUM. % < CUT	EMISSION FACTOR (LB/T)	EMISSION FACTOR (KG/MT)
.625	1.46364	.138883	.0694414
1	3.13028	.297029	.148514
1.25	4.99144	.473632	.236816
2.5	17.5865	1.66876	.834381
5	35.5683	3.37504	1.68752
10	54.6757	5.18812	2.59406
15	61.7131	5.85589	2.92795
20	65.8706	6.25039	3.12519

END OF TEST SERIES

SPLIN2 PROGRAM - 02/22/82 V1

TEST ID: SLOAN 1971 WASHER EXHAUST

INPUT DATA: PROCESS WEIGHT RATE = 225 TONS PROD. /HR
TOTAL PARTICULATE EMISSION RATE = 181 LB/HR
PARTICLE DENSITY = 1 G/CC

MEASURED PARTICLE SIZE DISTRIBUTION

CUT (um)	RAW % < CUT	CUM. % < CUT
.3	5.7	5.7
1	8	13.7
2	4.9	18.6
3.3	4.4	23
5.5	4.7	27.7
9.2	8.3	36
30	9.2	45.2
120	54.8	100

OUTPUT DATA: TP EMISSION FACTOR = .804444 LB/T (.402222 KG/MT)

CUT (umA)	CUM. % < CUT	EMISSION FACTOR (LB/T)	(KG/MT)
.625	10.2502	.0824569	.0412284
1	13.632	.109662	.0548311
1.25	15.1735	.122063	.0610313
2.5	20.51	.164992	.0824959
5	26.6368	.214278	.107139
10	36.513	.293727	.146863
15	38.9805	.312772	.156386
20	40.6257	.326811	.163406

END OF TEST SERIES

SPLIN2 PROGRAM - 02/22/82 V1

TEST ID: HARRISON 1971 PRE-WASH ENTRANCE

INPUT DATA: PROCESS WEIGHT RATE = 180 TONS PROD. /HR
TOTAL PARTICULATE EMISSION RATE = 1715 LB/HR
PARTICLE DENSITY = 1 G/CC

MEASURED PARTICLE SIZE DISTRIBUTION

CUT (um)	RAW % < CUT	CUM. % < CUT
2	14.9	14.9
5.5	35.1	50
30	26.9	76,9
120	23.1	100

OUTPUT DATA: TP EMISSION FACTOR = 9.52778 LB/T (4.76389 KG/MT)

CUT (umA)	CUM. % < CUT	EMISSION FACTOR (LB/T)	(KG/MT)
.625	1.53489	.146241	.0731205
1	4.3074	.4104	.2052
1.25	6.66173	.634714	.317357
2.5	20.6907	1.97136	.98568
5	45.5494	4.33985	2.16992
10	62.6116	5.9655	2.98275
15	68.0623	6.48482	3.24241
20	71.678	6.82932	3.41466

END OF TEST SERIES

SPLIN2 PROGRAM - 02/22/82 V1

TEST ID: HARRISON 1971 WASHER EXHAUST

INPUT DATA: PROCESS WEIGHT RATE = 180 TONS PROD. /HR
TOTAL PARTICULATE EMISSION RATE = 63 LB/HR
PARTICLE DENSITY = 1 G/CC

MEASURED PARTICLE SIZE DISTRIBUTION

CUT (um)	RAW % < CUT	CUM. % < CUT
2	88	88
5.5	6.8	94.8
30	2.2	97
120	3	100

OUTPUT DATA: TP EMISSION FACTOR = .35 LB/T (.175 KG/MT)

CUT (umA)	CUM. % < CUT	EMISSION FACTOR (LB/T)	(KG/MT)
.625	76.375	.267312	.133656
1	81.4615	.285115	.142558
1.25	83.7061	.292971	.146486
2.5	89.8065	.314323	.157161
5	94.2514	.32988	.16494
10	95.831	.335408	.167704
15	96.1995	.336698	.168349
20	96.4902	.337716	.168858

END OF TEST SERIES

REFERENCE 12 DATA

(From Table 3-10)

SPLIN2 PROGRAM - 02/22/82 V1

TEST ID: TABLE 94 AP-40 C-537 INLET TO PRIMARY CYCLONE

INPUT DATA: PROCESS WEIGHT RATE = 173 TONS PROD. /HR
TOTAL PARTICULATE EMISSION RATE = 5463 LB/HR
PARTICLE DENSITY = 2.4 G/CC

MEASURED PARTICLE SIZE DISTRIBUTION

CUT (um)	RAW % < CUT	CUM. % < CUT
5	6.2	6.2
10	9.4	15.6
20	13.8	29.4
50	22.9	52.3
74	47.7	100

OUTPUT DATA: TP EMISSION FACTOR = 31.578 LB/T (15.789 KG/MT)

CUT (umA)	CUM. % < CUT	EMISSION FACTOR (LB/T)	(KG/MT)
.625	.0186489	5.88895E-03	2.94447E-03
1	.0734769	.0232025	.0116013
1.25	.134485	.0424676	.0212338
2.5	.726412	.229387	.114693
5	2.93889	.928044	.464022
10	8.90582	2.81228	1.40614
15	14.8743	4.69702	2.34851
20	19.9991	6.31533	3.15766

END OF TEST SERIES

SPLIN2 PROGRAM - 02/22/82 V1

TEST ID: TABLE 94 AP-40 C-537 INLET TO SCRUBBER

INPUT DATA: PROCESS WEIGHT RATE = 173 TONS PROD. /HR
TOTAL PARTICULATE EMISSION RATE = 118.3 LB/HR
PARTICLE DENSITY = 2.4 G/CC

MEASURED PARTICLE SIZE DISTRIBUTION

CUT (um)	RAW % < CUT	CUM. % < CUT
5	57	57
10	34	91
20	8.8	99.8
50	.2	100
74	0	100

OUTPUT DATA: TP EMISSION FACTOR = .683815 LB/T (.341908 KG/MT)

CUT (umA)	CUM. % < CUT	EMISSION FACTOR (LB/T)	(KG/MT)
.625	.432684	2.95876E-03	1.47938E-03
1	1.56537	.0107042	5.35211E-03
1.25	2.71332	.0185541	9.27703E-03
2.5	11.6883	.0799265	.0399633
5	34.5881	.236518	.118259
10	70.3109	.480796	.240398
15	89.0992	.609273	.304637
20	95.5844	.653621	.32681

END OF TEST SERIES

SPLIN2 PROGRAM - 02/22/82 V1

TEST ID: TABLE 94 AP-40 INLET TO MULTICLONE

INPUT DATA: PROCESS WEIGHT RATE = 173 TONS PROD. /HR
TOTAL PARTICULATE EMISSION RATE = 1525 LB/HR
PARTICLE DENSITY = 2.4 G/CC

MEASURED PARTICLE SIZE DISTRIBUTION

CUT (um)	RAW % < CUT	CUM. % < CUT
5	19.3	19.3
10	31.9	51.2
20	31.6	82.8
50	15.1	97.9
74	2.1	100

OUTPUT DATA: TP EMISSION FACTOR = 8.81503 LB/T (4.40752 KG/MT)

CUT (umA)	CUM. % < CUT	EMISSION FACTOR (LB/T)	(KG/MT)
.625	8.38504E-03	7.39144E-04	3.69572E-04
1	.0582523	5.13496E-03	2.56748E-03
1.25	.135014	.0119015	5.95076E-03
2.5	1.32526	.116822	.0584111
5	7.92999	.699031	.349516
10	28.9263	2.54986	1.27493
15	48.896	4.3102	2.1551
20	63.2283	5.5736	2.7868

END OF TEST SERIES

REFERENCE 26 DATA

(From Table 3-11)

TITLE KVB 5806-783 Test # 295 Outlet

PROJECT NO. 4892L84 DRAWN JP APPR. DATE 7/16/82

Percent Actual Production Rate of the Design Production Rate = $\frac{227{,}000\ kg}{hr.} \times \frac{70}{100} = \frac{158{,}900\ kg}{hr}$

Process Weight Rate = $\frac{158{,}900\ kg}{hr.} \times \frac{1\ lb.}{.454\ kg.} \times \frac{1\ ton}{2000\ lbs.} = 175\ \frac{tons}{hr.}$

SPLIN2 PROGRAM - 02/22/82 V1

TEST ID: KVB 5806-783 TEST 29S OUTLET

INPUT DATA: PROCESS WEIGHT RATE = 175 TONS PROD. /HR
TOTAL PARTICULATE EMISSION RATE = 4.34 LB/HR
PARTICLE DENSITY = 1 G/CC

MEASURED PARTICLE SIZE DISTRIBUTION

CUT (um)	RAW % < CUT	CUM. % < CUT
1	30	30
3	4	34
10	6	40
120	60	100

OUTPUT DATA: *TP EMISSION FACTOR = .0248 LB/T (.0124 KG/MT)

CUT (umA)	CUM. % < CUT	EMISSION FACTOR (LB/T)	(KG/MT)
.625	28.6282	7.09981E-03	3.5499E-03
1	30	7.44E-03	3.72E-03
1.25	30.7175	7.61795E-03	3.80897E-03
2.5	33.2376	8.24293E-03	4.12146E-03
5	35.76	8.86849E-03	4.43424E-03
10	40.3701	.0100118	5.00589E-03
15	46.7671	.0115982	5.79912E-03
20	53.9065	.0133688	6.68441E-03

END OF TEST SERIES

*Calculated from input data above--not as shown on p. 4-165 of report (Appendix F).

APPENDIX K

EMISSIONS CALCULATIONS FOR DRUM-MIX ASPHALT PLANTS

(Results Included in Table 3-35)

MIDWEST RESEARCH INSTITUTE

PROJECT DEVELOPMENT SKETCH

MRI-18

TITLE Calculations for Candidate Emission Factors: Drum-Mix Asphalt Plants (Reference 27)

PROJECT NO. 4892-L84 DRAWN JSK APPR. _____ DATE 11/4/82

Particle Size Distribution: Uncontrolled Emissions (From Table 3-2

For Particles < 15 μmA - Uncontrolled

$$\frac{8.2 \text{ lbs/ton}}{30.9 \text{ lbs/ton}} \times 100 = 26.5\%$$

For Particles < 10 μmA - Uncontrolled

$$\frac{7.2 \text{ lbs/ton}}{30.9 \text{ lbs/ton}} \times 100 = 23.3\%$$

For Particles < 2.5 μmA - Uncontrolled

$$\frac{1.7 \text{ lbs/ton}}{30.9 \text{ lbs/ton}} \times 100 = 5.5\%$$

Particle Size Distribution: Controlled Emissions (From Table 3-28)

For Particles < 15 μmA - Controlled

$$\frac{0.023 \text{ lbs/ton}}{0.065 \text{ lbs/ton}} \times 100 = 35.4\%$$

For Particles < 10 μmA - Controlled

$$\frac{0.021 \text{ lbs/ton}}{0.065 \text{ lbs/ton}} \times 100 = 32.3\%$$

For Particles < 2.5 μmA - Controlled

$$\frac{0.007 \text{ lbs/ton}}{0.065 \text{ lbs/ton}} \times 100 = 10.8\%$$

Emission Factors - Uncontrolled

From Table 8.1-5 of AP-42: Total Particulate = 2.45 kg/Mg

$$\therefore \quad 2.45 \frac{\text{kg}}{\text{Mg}} \times 0.265 \frac{\text{kg part. < 15 μmA}}{\text{kg total mass}} = 0.649 \frac{\text{kg}}{\text{Mg}} \text{ < 15 μmA}$$

$$2.45 \frac{\text{kg}}{\text{Mg}} \times 0.233 \frac{\text{kg. part. < 10 μmA}}{\text{kg total mass}} = 0.571 \frac{\text{kg}}{\text{Mg}} \text{ < 10 μmA}$$

$$2.45 \frac{\text{kg}}{\text{Mg}} \times 0.055 \frac{\text{kg part. < 2.5 μmA}}{\text{kg total mass}} = 0.135 \frac{\text{kg}}{\text{Mg}} \text{ < 2.5 μmA}$$

Emission Factors - Controlled (use overall collection efficiency of baghouse applied to above uncontrolled emission factor)

Baghouse Efficiency: Data from Tables 3-27 & 3-28

$$\frac{30.9 \text{ lbs/ton} - 0.065 \text{ lbs/ton}}{30.9 \text{ lbs/ton}} \times 100 = 99.79\%$$

Controlled Total Particulate Emission Factor:

$$2.45 \frac{\text{kg}}{\text{Mg}} \times (1 - 0.998) = 0.0049 \frac{\text{kg}}{\text{Mg}}$$

Size Specific Emission Factors:

For Particles < 15 μmA – 35.4% of total mass

$$0.0049 \frac{kg}{Mg} \times 0.354 = 0.00173 \frac{kg}{Mg}$$

For Particles < 10 μmA – 32.3% of total mass

$$0.0049 \frac{kg}{Mg} \times 0.323 = 0.00158 \frac{kg}{Mg}$$

For Particles < 2.5 μmA – 10.8% of total mass

$$0.0049 \frac{kg}{Mg} \times 0.108 = 5.29\,(10)^{-4} \frac{kg}{Mg}$$

Condensable Organic Emission Factor:

From Table 3-29 – subtract the < 2.5 μm emission factor from the IP train from that obtained from the stack dilution system

Run #2:

$$0.0057 \frac{lbs}{ton} - 0.00055 \frac{lbs}{ton} = 0.0051 \frac{lbs}{ton}$$

Run #3

$$0.0066 \frac{lbs}{ton} - 0.00060 \frac{lbs}{ton} = 0.006 \frac{lbs}{ton}$$

Run #4

$$0.013 \frac{lbs}{ton} - 0.0011 \frac{lbs}{ton} = 0.0119 \frac{lbs}{ton}$$

Average Emission Factor:

$$\frac{(0.0051 + 0.0060 + 0.012)}{3} = 0.0077 \frac{\text{lbs}}{\text{ton}}$$

$$7.7(10)^{-3} \frac{\text{lbs}}{\text{short ton}} \times 1.1 \frac{\text{short ton}}{\text{metric ton}} \times 454 \frac{\text{gm}}{\text{lb}} \times \frac{1\ \text{kg}}{10^3\ \text{gm}} \times \frac{1\ \text{MT}}{1\ \text{Mg}} = 3.85(10)^{-3} \frac{\text{kg}}{\text{Mg}}$$

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(Please read Instructions on the reverse before completing)

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15. SUPPLEMENTARY NOTES AEERL project officer is Dale L. Harmon, Mail Drop 61, 919/541-2429.

16. ABSTRACT The report describes the development of particulate emission factors based on cutoff size for inhalable particles for the asphaltic concrete industry. After review of available information characterizing particulate emissions from asphalt concrete plants, the data were summarized and rated in terms of reliability. Size specific emission factors were developed from these data for each of the three processes used in the manufacture of asphalt concrete. A detailed process description is presented, with emphasis on factors affecting the generation of emissions. A replacement for Section 8.1 (Asphalt Concrete Plants) of AP-42 was prepared, containing the size specific emission factors developed by the program.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Pollution	Pollution Control	13B
Bituminous Concretes	Stationary Sources	11B, 13C
Asphalt Plants	Asphalt Concrete Plants	13I
Dust	Particulate	11G
Emission	Emission Factors	14G

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