CONTROL TECHNIQUES FOR ASBESTOS AIR POLLUTANTS

U. S. ENVIRONMENTAL PROTECTION AGENCY

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ENVIRONMENTAL PROTECTION AGENCY
Office of Air and Water Programs
Office of Air Quality Planning and Standards
Research Triangle Park, North Carolina 27711
February 1973

For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402

The AP series of reports is published by the Technical Publications Branch of the Information Services Division of the Office of Administration for the Office of Air and Water Programs, Environmental Protection Agency, to report the results of scientific and engineering studies, and information of general interest in the field of air pollution. Information reported in this series includes coverage of intramural activities and of cooperative studies conducted in conjunction with state and local agencies, research institutes, and industrial organizations. Copies of AP reports are available free of charge to Federal employees, current contractors and grantees, and nonprofit organizations – as supplies permit – from the Air Pollution Technical Information Center, Environmental Protection Agency, Research Triangle Park, North Carolina 27711, or from the Superintendent of Documents.

Publication No. AP-117

PREFACE

This document contains information about the nature and control of a hazardous air pollutant – asbestos. The primary purpose of this document is to provide information useful to those involved in the control of emissions of asbestos from industrial sources. The language and approach are largely technical, but the first two sections should be of interest and value to the general reader.

The requirement to publish this document was established when the Administrator of the Environmental Protection Agency listed asbestos as a hazardous air pollutant by notice in the *Federal Register* (Vol. 36, p. 5931) on March 21, 1971. The Administrator acted under the authority granted him by Section 112 of the Clean Air Act, which defines a hazardous air pollutant as "... an air pollutant to which no ambient air quality standard is applicable and which in the judgment of the Administrator may cause, or contribute to, an increase in mortality or an increase in serious irreversible, or incapacitating reversible, illness."

Mr. J.U. Crowder and Mr. G.H. Wood of the Office of Air and Water Programs, Environmental Protection Agency, were primarily responsible for compiling the information contained in this document. This information represents the efforts of the Environmental Protection Agency, as well as the advice of the members of the advisory committee listed on the following pages and the contributions of many individuals associated with other Federal agencies, State and local governments, and private industry.

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ABSTRACT

Asbestos is the generic name for a group of hydrated mineral silicates that occur naturally in a fibrous form. The technological utility of asbestos derives from its physical strength, resistance to thermal degradation, resistance to chemical attack, and ability to be subdivided into fine fibers.

The subdivision of asbestos into fine fibers produces particulate matter that is readily dispersed into the atmosphere. Adverse effects of airborne asbestos on human health have been associated primarily with direct and indirect occupational exposures, but a level of asbestos exposure below which there is no detectable risk of adverse health effects to the general population has not yet been identified. Because of the lack of a practical technique of adequate sensitivity for measuring small concentrations of airborne asbestos, neither accurate emission factors nor emission-effect relationships are available.

Engineering appraisals, based on limited data, indicate that the milling and basic processing of asbestos ore (crushing and screening the ore and aspirating the fiber to cyclones for grading) and the manufacture of asbestos-containing friction materials, asbestos-cement products, vinyl-asbestos tile, asbestos textiles, and asbestos paper account for over 85 percent of total asbestos emissions. Other sources include: (1) the manufacture of other products containing asbestos, such as paints, coatings, adhesives, plastics, rubber materials, and molded insulating materials; (2) the use of spray-on asbestos products, such as those used for fireproofing or insulating; (3) the demolition of buildings or structures containing asbestos fireproofing or insulating materials; and (4) the sawing, grinding, or machining of materials that contain asbestos, such as brake linings and molded pipe insulation. In most of the manufacturing operations, the major emissions of asbestos occur when the dry asbestos is being handled, mixed with other dry materials, or dumped into the wet product mix, but the weaving of asbestos fibers into textiles and the machining or sanding of hard asbestos products also produce major emissions.

Emissions are controlled in several ways: (1) by careful handling of dry materials to avoid generating dust; (2) by enclosing dusty operations; (3) by substituting wet processes for dry processes; (4) by wetting dry materials before handling, sawing, or grinding; (5) by cleaning the dust-laden air by drawing it into ducts that lead to fabric filters; and (6) by reducing the amount of asbestos added to products the use of which leads to the generation of emissions. The last technique is particularly applicable to situations where the control of emissions by other methods is very difficult, as with spray application of insulation or demolition of structures. The costs of needed emission control techniques can be estimated from those associated with existing practices.

Key words: asbestos emissions, control techniques, costs.

SUMMARY

BACKGROUND INFORMATION

Asbestos is the generic name for a group of naturally occurring, hydrated, mineral silicates. Asbestos can be separated into fine fibers and further subdivided into even finer fibrils, as small as approximately 0.03 micrometer (μm) in diameter, which contribute to particulate air pollution. To date, the evidence of an association between exposure to airborne asbestos and adverse effects on human health has been restricted primarily to direct and indirect occupational exposures. A level of asbestos exposure below which there is no detectable risk of adverse health effects to the general population has not yet been identified.

Most measurements of asbestos fiber concentrations in industrial environments are economically practical only for those fibers visible by light microscopy, and an analytical technique that employs 430X magnification and phase contrast illumination has been standardized. Fiber counts obtained more recently by the application of electron microscopy have revealed that only a small percentage of the total population of fibers present in a sample is included in the data obtained by light microscopy. Numerous technical problems remain to be resolved, however, before a standardized method can be adopted that enumerates total numbers of fibers and fibrils in a sample by use of the electron microscope.

Asbestos is domestically mined in only four states, and approximately five-sixths of the asbestos consumed in the United States is imported. Asbestos is used in a vast array of products ranging from those that take advantage of its resistance to thermal attack to the numerous products in which it serves as a filler material.

Estimates of emissions indicate that the extraction of asbestos from ore constitutes the largest single domestic source of atmospheric asbestos. A number of industrial processes associated with the manufacture of asbestos-containing products are also significant sources of emissions. Several end uses of asbestos contribute emissions in the process of installation or application of the material and/or during an extended period of product usage.

ASBESTOS EMISSION SOURCES AND CONTROL TECHNIQUES

Mining

The mining of asbestos ores is accompanied by emissions from drilling for explosive charges; surface scraping, screening, and ore loading at mines; transportation to mills; unloading at mills; and exposure of mine waste and ore piles to the atmosphere. Adequate control by gas cleaning has been achieved only for drilling operations. Quite limited progress has been made toward preventing asbestos-bearing material in exposed deposits, such as ore deposits and tailings dumps, from becoming entrained in the atmosphere; such limited control has been achieved by providing vegetation cover for the deposits or, for temporary deposits, by employing surface wetting. Emissions generated during transportation can be diminished by surface wetting, use of vehicle covers, or use of enclosed vehicle bodies. Blasting and the various handling operations are, at present, essentially uncontrolled.

Basic Processing

In the milling or basic processing of asbestos ores, direct emission sources are exposed ore and tailings piles, effluents of ore crushers, exhausts of ore dryers, and atmospheric exhausts of mill ventilation and/or process air. Emissions to a mill work space originate from numerous screening operations, transport of dry asbestos-containing materials by conveyor systems, and packaging of asbestos. Emissions from some ore dryers operated by the Canadian asbestos industry are now controlled by thermally insulated, fabric filter collectors; this control method is undergoing further development. Emissions of asbestos in ventilation and process air streams from mill buildings are frequently controlled by the use of fabric filters; a prime requirement for the attainment of design collection efficiency is a strict maintenance program for the collector. Emissions from ore crushers and vibrating screens have been controlled to some extent by fitting ventilated enclosures or dust-capture hoods to the equipment and by cleaning the ventilation streams by means of fabric filters. Some conveyors have been completely enclosed as an emission control measure.

Manufacturing

Emission sources within plants that manufacture asbestos-containing products are important because a portion of the plant ventilation air always reaches the exterior environment. Because atmospheric emissions can be controlled through the application of fabric filters, the task of overall emission control is largely one of capturing airborne local emissions from various manufacturing processes and conveying the fibers to the filter. These processes include handling and dumping of asbestos contained in bags, dry mixing of asbestos-containing materials, dry-processing operations, finish machining of products, and packaging. Dust capture hoods, some of which are generally applicable for ventilating dust-producing operations such as bag opening and others of which are tailored to remove dust from specific pieces of equipment such as textile carding machines, are widely employed at present. The adoption of good housekeeping practices that are accompanied, for example, by central vacuuming systems is another effective control method. In some instances, emissions can be controlled by substituting a wet process for a dry one.

End Uses

An emission control technique applicable to some end uses of asbestos-containing products is the elimination of asbestos in favor of substitute materials. Sprayed insulation materials that contain no asbestos are now in use, and it is anticipated that asbestos-free molded pipe insulation will be marketed in the near future. Shielding of work spaces from the exterior environment and use of good housekeeping practices are the primary control measures, aside from the use of asbestos-free materials, that have been used to control emissions from spraying of fireproofing and the field installation of products containing asbestos. Also, dust capture hoods for the local collection of machining wastes are available for both stationary and portable power tools.

Control techniques for the handling and final disposal of waste products containing asbestos are currently available in the form of recommended handling and disposal practices. These have not been widely adopted.

Asbestos emissions, in some instances, can be controlled by techniques other than the utilization of gas cleaning devices. External conveyors can be enclosed, storage and tailings piles can be coated with dust suppressants, and spray fireproofing and insulating products containing little or no asbestos can be developed at costs that are not unreasonable relative to total plant investment and/or product value.

COSTS OF CONTROL BY GAS CLEANING DEVICES

Air pollution control costs for gas cleaning by dry centrifugal collectors, wet collectors, and fabric filters can be estimated by evaluating average costs for capital investment, maintenance, and operation. Installed equipment costs can be expressed as percentages of equipment purchase costs for a wide range of special conditions that influence applications to differing processes. Ranges of annual maintenance costs, per unit of gas handling capacity, facilitate estimates among differing practices of control equipment operators as well as among the three types of control devices. By combining the estimates of the various facets, the total cost of control can be appraised.

EVALUATION OF ASBESTOS EMISSIONS

Emission factors are useful in estimating rates and quantities of atmospheric emissions from sources in the absence of measurements of emissions from stacks and other points of introduction into the atmosphere; however, accurate asbestos emission factors are not currently available. Extensive emissions testing data must be compiled if reliable estimates of mass rate emission factors and their relation to fiber concentrations are to be determined.

GAS CLEANING DEVICES

Brief descriptions of geometrical configurations, principles of operation, and performance characteristics of fabric filters, dry centrifugal collectors, and wet collectors are presented in an appendix in which specific design parameters and operational features of fabric filters in use in asbestos mills and plants that manufacture asbestos-containing products are also discussed.

CONTROL TECHNIQUES FOR ASBESTOS AIR POLLUTANTS

1. INTRODUCTION

Control Techniques for Asbestos Air Pollutants is issued in accordance with Section 112 (b) (2) of the Clean Air Act as amended by the Clean Air Amendments of 1970.

The existence of an association between human disease and inhaled asbestos has been known for a half-century. In the main, these relationships have been established within groups that have experienced indirect or direct occupational exposures; the range of activities extends from mining and milling of asbestos to the manufacture of asbestos textiles to the application and eventual removal of asbestos-containing insulation materials. The conjecture that large segments of the general population of the United States might be exposed to asbestos to the extent that adverse health effects would result is of more recent origin. Accordingly, the need for more stringent control of asbestos emissions into the atmosphere has been recognized.

Asbestos is emitted from both stationary and mobile sources. Emissions of asbestos resulting from the wearing of large numbers of motor vehicle brake linings are the subject of current investigation; the extent to which asbestos in the waste particulates has been thermally degraded prior to emission is in question.

Technology in the form of specific gas cleaning devices can control asbestos emissions from many source categories with high efficiency; corresponding air pollution control costs are moderate. For example, installations that routinely recycle large volumes of cleaned process and ventilation air back to work spaces for general ventilation are in operation. These control methods, however, are practiced in the absence of a thorough knowledge of either the equipment collection efficiencies for submicron particulates or the potential adverse health effects of these smallest fibers.

The nature of some operations that accompany mining and milling of asbestos ores precludes, in a practical sense, emission control by gas cleaning methods. Control techniques applicable to blasting, storage of large quantities of raw ore, transportation on roadways surfaced with asbestos-containing wastes, and disposal of mine wastes and mill tailings are available to reduce emissions, ever, through the application of wetting agents and surface coatings. Other operations ranging from rock drilling at mines to ore crushing, drying, and screening in mills are amenable to emission control by gas cleaning devices.

Asbestos emissions result from numerous processes in the manufacture of a vast array of products that contain asbestos as either a primary or subsidiary component. Available control techniques are based upon the containment of potential emissions at the source or upon the entrainment, at the source, of potential emissions and waste into an air stream that is subsequently cleaned. Other emission control methods substitute a wet process for a conventional, dry technique.

End-uses of asbestos-containing products, particularly those that are friable, can be accompanied by emissions during installation, during an extended period of usage, and ultimately during final demolition or disposal. In recognition of the extreme difficulty of controlling emissions from a relatively small number of these products, substitute materials for asbestos have been adopted, and development of appropriate substitutes for inclusion in additional products is in progress. The adoption of the following measures constitutes a generalized control technique for emissions from the usage, conversion to waste, and disposal of asbestos-containing products:

1. Identification of significant sources of direct exposure of the general population to asbestos emissions.

2. Development of an appreciation for the adverse effects of asbestos on human health on the part of all workers who handle asbestos-containing materials.

3. Application of existing control technologies for dust containment, capture, and collection.

4. Enforcement of appropriate methods for the disposal of asbestos-containing wastes.

Some estimates of quantities of asbestos emitted to the atmosphere are presented herein. Discussion of the specific effects of asbestos on human health is, however, outside the scope of this report.

2. BACKGROUND INFORMATION

2.1 DEFINITIONS

The term "asbestos" refers to any of six naturally occurring crystalline mineral silicates: actinolite, amosite, anthophyllite, chrysotile, crocidolite, and tremolite.[1] Each of these materials is a hydrated silicate; the degree of hydration varies from approximately 1.5 percent in some deposits of crocidolite to approximately 14.5 percent in the majority of the deposits of chrysotile.[1] These minerals display a wide range of chemical compositions, as is indicated in Table 2-1.

The several types of asbestos were formed by the metamorphosis of serpentine and amphibole minerals, both classes of which contain silica. Chrysotile, which is a hydrated silicate of magnesia, is the principal crystalline form of serpentine. The remaining five types of asbestos are crystalline forms of amphibole minerals. Crocidolite, frequently called blue asbestos, is associated with riebeckite. Amosite is the only asbestos of grunerite that is of commercial value. Anthophyllite is thought to be evolved from the metamorphosis of olivine. Tremolite occurs in crystalline, dolomitic limestone and is called actinolite when iron is present in amounts greater than 2 percent.[1]

The technological utility of asbestos derives from its occurrence in a fibrous state and from its properties of exceptional physical strength, resistance to thermal degradation, and resistance to attack by acids or alkalis in one or more of the materials. For example, slender chrysotile "fibers" with lengths exceeding 3/4-inch are commercially available; subsequent to blending with small quantities of synthetic or organic fibers, these asbestos "fibers" can be spun into yarn and then converted into a variety of textile products. Each asbestos "fiber" can usually be subdivided into a large number of "fibers" of the original length. This feature permits significant alterations in the transverse stiffness, or flexibility, of "fibers" of given length to be made by controlling the degree of subdivision or opening of the "fibers" in an asbestos milling process.

Electron microscopy reveals that the smallest fibrous subdivision of a chrysotile fiber, called a fibril, has an average outside diameter of 0.034 micrometer (μm). Further, it has been shown that the chrysotile fibril is a hollow tube, rather than a solid cylinder, with an average inside diameter of 0.018 μm.[2] A suggested model views the chrysotile fiber as a tightly packed collection of fibrils, the interiors and interstices of which are filled with crystal fragments or amorphous material of the same chemical composition; the interfibril binding forces are relatively weak.[5] The elementary crystal structure, or fibril, of the amphibole asbestoses forms a solid cylinder considerably larger in outside diameter than the chrysotile fibril; the average outside diameter ranges from 0.1 to 0.2 μm.[2] Although the majority of dry-milled asbestos fibers each contain many fibrils, smaller numbers of fibers composed of only one or two fibrils are always present; a considerable number of these fibers of smaller diameter are found in asbestos dust.[5]

2.2 PHYSICAL, CHEMICAL, AND MINERALOGICAL PROPERTIES OF ASBESTOS

Table 2-1 ranks the six varieties of asbestos according to such physical characteristics as spinability and flexibility of

Table 2-1. PHYSICAL, CHEMICAL, AND MINERALOGICAL PROPERTIES OF VARIETIES OF ASBESTOS[2,3]

Property	Chrysotile	Crocidolite	Amosite	Anthophyllite	Tremolite	Actinolite
Chemical formula	$Mg_3Si_2O_5(OH)_4$	$Na_2Fe_5Si_8O_{22}(OH)_2$	$(FeMg)_6Si_8O_{22}(OH)_2$	$(FeMg)_7Si_8O_{22}(OH)_2$	$Ca_2Mg_5Si_8O_{22}(OH)_2$	$(CaMgFe)_6Si_8O_{22}(OH)_2$
Essential composition	Hydrous silicate of magnesia	Silicate of sodium and iron with some water	Silicate of iron and magnesium, higher iron than anthophyllite	Magnesium silicate with iron	Calcium and magnesium silicate with some water	Calcium-magnesium-iron silicate; water up to 5%
Percentage chemical composition						
SiO_2	37. to 44.	49. to 53.	49. to 53.	56. to 58.	51. to 62.	--
MgO	39. to 44.	0. to 3	1. to 7.	28. to 34.	0. to 30.	--
FeO	0.0 to 6.0	13. to 20.	34. to 44.	3. to 12.	1.5 to 5.0	--
Fe_2O_3	0.1 to 5.0	17. to 20.	--	--	--	--
Al_2O_3	0.2 to 1.5	--	2. to 9.	0.5 to 1.5	1.0 to 4.0	--
H_2O	12.0 to 15.0	2.5 to 4.5	2. to 5.	1.0 to 6.0	0. to 5.0	--
CaO	trace to 5.0	--	--	--	0. to 18.	--
Na_2O	--	4.0 to 8.5	--	--	0. to 9	--
CaO and Na_2O	--	--	0.5 to 2.5	--	--	--
pH	9.2 to 9.8	--	--	Neutral	--	--
Resistance to acids	Poor	Good	--	--	Good	Good
Veining	Cross and slip fibers	Cross fiber	Cross fiber	Slip, mass fiber unoriented and interlacing	Slip or mass fiber	Slip or mass fiber
Color	Green, gray, amber to white	Blue	Gray, yellow to dark brown	Yellowish brown, grayish white	Gray-white, greenish, yellowish, bluish	Greenish
Texture	Soft to harsh, also silky	Soft to harsh	Coarse but somewhat pliable	Harsh	Generally harsh, sometimes soft	Harsh
Luster	Silky	Silky to dull	Vitreous, somewhat pearly	Vitreous to pearly	Silky	Silky
Hardness[a]	2.5 to 4.0	4	5.5 to 6.0	5.5 to 6.0	5.5	6±
Flexibility	High	Good	Good	Poor	Poor	Poor
Spinnability	Very good	Fair	Fair	Poor	Poor	Poor
Tensile strength, lb/in^2	824,000 max.	876,000 max	16,000 to 90,000	4,000 and less	1,000 to 8,000	1,000 and less
Fusion point, °F	2,770	2,180	2,550	2,675	2,400	2,540
Specific heat, Btu/lb-°F	0.266	0.201	0.193	0.210	0.212	0.217

Table 2-1. (continued) PHYSICAL, CHEMICAL, AND MINERALOGICAL PROPERTIES OF VARIETIES OF ASBESTOS

Property	Chrysotile	Crocidolite	Amosite	Anthophyllite	Tremolite	Actinolite
Electric charge	Positive	Negative	Negative	Negative	Negative	Negative
Filtration properties	Slow	Fast	Fast	Medium	Medium	Medium
Specific gravity	2.4 to 2.6	3.2 to 3.3	3.1 to 3.25	2.85 to 3.1	2.9 to 3.2	3.0 to 3.2
Cleavage	010 perfect	110 perfect	110 perfect	110 perfect	110 perfect	110 perfect
Optical properties	Biaxial positive, extinction parallel	Biaxial ±, extinction inclined	Biaxial positive, extinction parallel	Biaxial positive, extinction parallel	Biaxial negative, extinction inclined	Biaxial negative, extinction inclined
Refractive index	1.50 to 1.55	1.7 pleochroic	1.64±	1.61±	1.61±	1.63± weakly pleochroic
Resistance to destruction by heat	Good, brittle at high temperatures	Poor, fuses	Good, brittle at high temperatures	Very good	Fair to good	--
Temperature at ignition loss, °F	1,800	1,200	1,600 to 1,800	1,500	1,800	--
Magnetite content, %	0.0 to 5.0	3.0 to 5.9	0	0	0	--
Crystal structure	Fibrous and asbestiform	Fibrous	Prismatic, lamellar to fibrous	Prismatic, lamellar to fibrous	Long and thin columnar to fibrous	Long and thin columnar to fibrous
Crystal system	Monoclinic and orthorhombic	Monoclinic	Monoclinic	Orthorhombic	Monoclinic	Monoclinic
Mineralogical structure	In veins of serpentine, etc	Fibrous in iron stones	Lamellar, coarse to fine fibrous and asbestiform	Lamellar, fibrous asbestiform	Long, prismatic and fibrous aggregates	Reticulated long prismatic crystals and fibers
Mineral association	In altered peridotite adjacent to serpentine and limestone near contact with basic igneous rocks	Iron rich silicious argillite in quartzose schists	In crystalline schists, etc.	In crystalline schists and gneisses	In Mg limestones as alteration product of magnesian rocks, metamorphic and igneous rocks	In limestones and in crystalline schists

[a]Working Scale of Hardness 1, very easily scratched by fingernail, and has greasy feel to the hand, 2, easily scratched by fingernail; 3, scratch by brass pin or copper coin; 4, easily scratched by knife, 5, scratch with difficulty with knife, 6, easily scratched by file; 7, little touched by file, but will scratch window glass. All harder than 7 will scratch window glass.[4]

fibers, resistance to destruction by heat, and resistance to the action of acids. Physical characteristics together with pertinent physical properties, such as tensile strength, govern the application of asbestos to numerous end-uses. Mineralogical properties, such as the veining of fibers, mineralogical structure, and mineral association, are relevant to the mining of asbestos-containing ores. Chemical compositions are also listed in Table 2-1.

2.3 ORIGINS AND USES OF ASBESTOS

Production of asbestos in the United States in 1970 totaled 125,314 short tons and was valued at an estimated $10,696,000.[6] Approximately 60 percent of the total was chrysotile mined in California by four producers located in Calaveras, Fresno, and San Benito counties. In decreasing rank, the remainder was mined in the states of Vermont (one producer, Orleans County, chrysotile), Arizona (three producers, Gila County, chrysotile), and North Carolina (one producer, Yancey and Jackson counties, anthophyllite). The apparent consumption of asbestos by the United States in 1970 amounted to 728,131 short tons.[6] Figure 2-1 illustrates the relationship between net imports and domestic production for the United States during the period 1960 to 1970.

As listed in Table 2-2, the world production of asbestos for 1969 was 3,640,017 short tons. The preliminary estimates of 1970 production for the three largest suppliers are 1,663,355 short tons for Canada; 1,150,000 short tons for the U.S.S.R.; and 316,822 short tons for the Republic of South Africa. Chrysotile from Canada and crocidolite from Africa constitute the majority of asbestos imported into the United States. The six mining areas of Asbestos, Black Lake, Coleraine, East Broughton, Robertson, and Thetford Mines in the southern portion of the Canadian province of Quebec are of particular interest as potential emission sources because of their proximity to the United States. The Canadian asbestos deposits are located between Danville and East Broughton in an area approximately 70 miles in length by 5 to 6 miles in width.

The major categories of asbestos usage are listed in Table 2-3 together with the corresponding 1968 United States apparent consumption and the range of asbestos content for the individual classifications.

2.4 CHARACTERIZATION OF EMISSION FORMS

The biological effects of asbestos are assumed to be related to concentrations of those fibers that are respirable. In numerous instances, individual fibers embedded in lung tissue of persons occupationally exposed to asbestos have been observed; the fibers have been identified as asbestos in some cases.[9] Accordingly, the quantitative specification of amounts of airborne asbestos should emphasize the number of fibers, or particles, per unit volume of gas rather than the mass concentration of entrained asbestos fibers.

Even the geometrical characterization of asbestos emissions presents a number of technical difficulties. These difficulties are largely related to the relative ease with which the extremely small-diameter fibrils of asbestos, both chrysotile and amphibole, can be separated from larger fiber bundles.[5] Crude milling of asbestos can yield fibers exceeding 2 inches in length with diameters up to 1/32 inch. Fundamental fibrils, however, some with lengths only slightly greater than the diameters, are present in large numbers in asbestos dust.[5] Fibers sometimes preferentially subdivide at the extremities and exhibit longer residence times in air as a result of the increased drag force.[5] Further, there is a tendency of very small asbestos particles to agglomerate and form much larger masses of fluff.[5]

The hydraulic beneficiation of asbestos ore, carried out in the United States by a single facility, produces asbestos that is

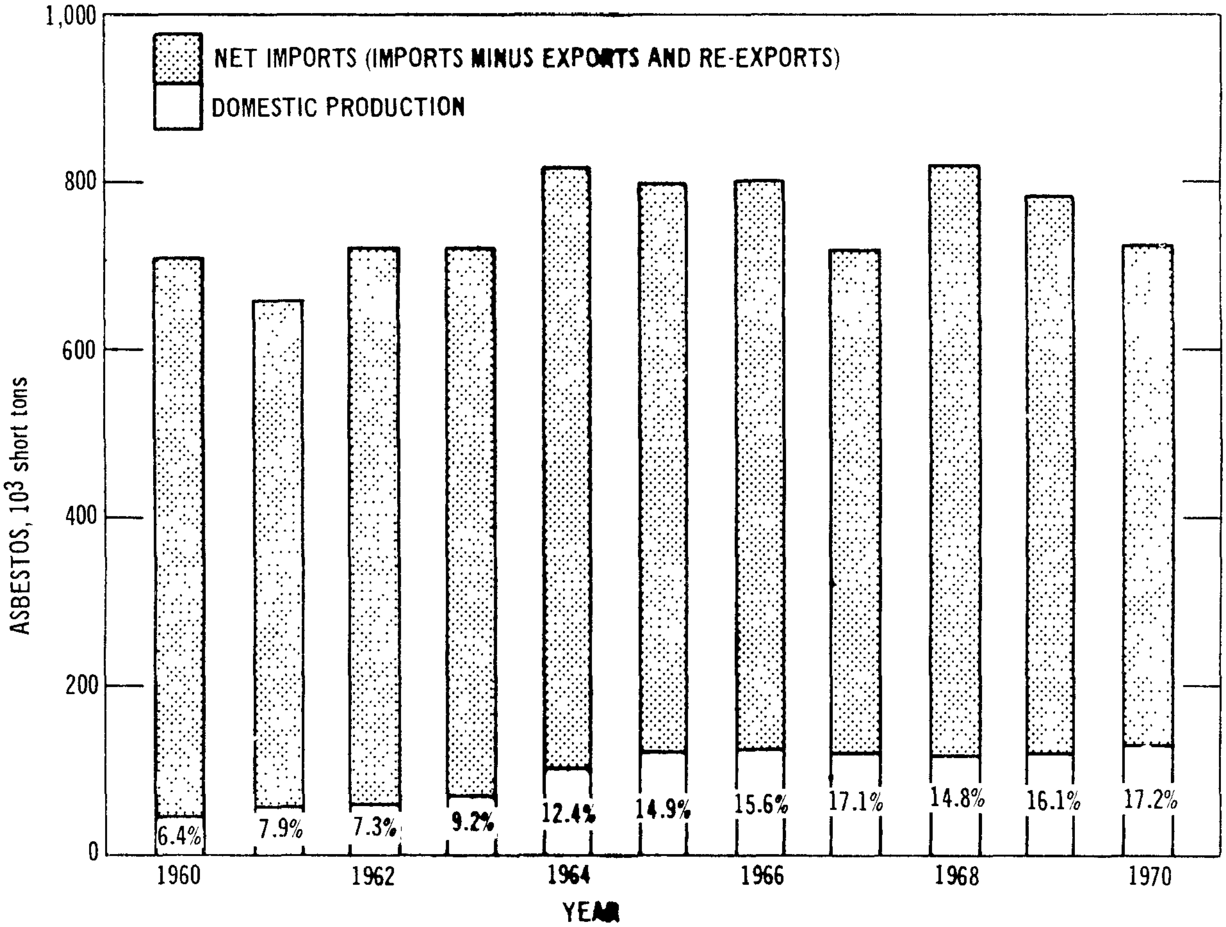

Figure 2-1. Domestic supply of asbestos.[5]

almost entirely separated into fibrils, which are subsequently consolidated into pellet form without the use of a binder. The process utilizes short-fiber Coalinga ore. Most of the fibrils have a length-to-diameter ratio of between 100 and 1000; the average ratio is approximately 200, and the average fiber length is about 5 μm. Small numbers of fibrils with a length-to-diameter ratio as small as unity are also present. The most effective dry milling processes applied to Coalinga ore do not produce such extensive separation into fibrils.[10]

Apart from the collection of meaningful samples of asbestos from emission streams, which can probably be effected in many cases by the application of membrane filters and particulate sampling trains,[9] the counting of asbestos fibers is a formidable task. Table 2-4 lists fiber size distributions for emissions from manufacturing operations in the asbestos textile, asbestos friction products, asbestos-cement, and asbestos insulation industries;[11] the percentages of fibers longer than 5μm and longer than 10μm were determined from counts of fibers visible at 430X magnification with phase-contrast illumination. The extent to which an increase in magnification from 430X to 970X resolves larger total numbers of fibers and larger numbers of fibers with lengths exceeding 5μm is shown in Table 2-5.[11] The data of Table 2-5 indicate that improved magnification increases resolution of the total number of visible fibers and the number of fibers longer than 5μm by approximately the same factor; therefore, fiber visibility is governed by resolution of the diameter at these levels of magnification.

With the electron microscope, sufficient

Table 2-2. WORLD PRODUCTION OF ASBESTOS BY COUNTRIES[a],[6]

(Short tons)

Country	1968	1969	1970[b]
North America			
Canada (sales)	1,509,699	1,576,876	1,663,355
United States (sold or used by producers)	120,690	125,936	125,314
Latin America			
Argentina	381	359	350[c]
Bolivia	1	—	—
Brazil	4,806	9,981	14,330
Europe			
Bulgaria	2,300[d]	3,100	3,900[c]
Finland[e]	14,484	15,487	15,019
France	551	550[c]	550[c]
Italy	114,020	124,039	130,747
Portugal	94[d]	224	200
U.S.S.R.[c]	900,000	1,100,000	1,150,000
Yugoslavia	11,456	12,634	13,342
Africa			
Mozambique	132	868	NA[f]
Rhodesia, Southern[c]	95,000	88,000	88,000
South Africa, Republic of	260,531	284,588	316,822
Swaziland	42,946	43,086	43,100[c]
United Arab Republic	2,868	—	—
Asia			
China, mainland[c]	170,000	180,000	190,000
Cyprus	21,293	23,927	28,253
India	9,992	10,734	10,840
Japan	24,251	23,148	23,576
Korea, Republic of (South)	3,650	6,515	1,513
Philippines	35	49	1,337
Taiwan	1,323	3,396	3,133
Turkey	3,905[d]	5,698	1,857
Oceania: Australia	895	822	700[c]
Total	3,315,303	3,640,017	3,826,238

[a]In addition to the countries listed, Czechoslovakia, North Korea, and Romania also produce asbestos, but information is insufficient to make reliable estimates of output levels.

[b]Preliminary.

[c]Estimate.

[d]Revised.

[e]Includes asbestos flour.

[f]Not available.

magnification is available to render visible all fibers of interest; Table 2-6 lists median fiber lengths and percentages of all visible fibers that exceed 5 μm in length for some of the manufacturing operations of Table 2-5. Only small percentages of the total numbers of fibers emitted from the various operations are longer than 5 μm; therefore, the standardized analytical techniques that employ 430X magnification count only small fractions of

Use	Apparent asbestos consumption, 10^3 short tons	Percent asbestos
Asbestos-cement products	566	15 to 30
Asbestos-containing floor tile	82	10 to 30
Asbestos paper	57	80 to 90
Asbestos-containing friction materials	25	30 to 80
Asbestos-containing paints, roof coatings, and caulks	16	–
Asbestos textiles	16	80 to 100
Asbestos-containing plastics	8	0.5 to 60[b,8]
Miscellaneous asbestos-containing products	47	–

[a]*Estimated from data for individual Standard Industrial Classification (SIC) Codes.*

[b]Includes products in which asbestos is used as a thixotrope.

Table 2-4. FIBER SIZE DISTRIBUTIONS BY MANUFACTURING OPERATION[a,11]

Operation	Percent total fibers	
	>5μm	>10μm
Asbestos textiles		
Fiber preparation and carding	50	25
Spinning, twisting, and weaving	61	38
Asbestos friction products		
Mixing	68	30
Grinding, cutting, and drilling	63	31
Asbestos-cement pipe		
Mixing	57	28
Finishing	58	27
Asbestos insulation		
Mixing	55	27
Finishing	50	29

[a]Fiber counts made at 430X magnification with phase–contrast illumination.

Table 2-5. RATIO BETWEEN FIBER SIZE DISTRIBUTION AT 970X AND 430X BY MANUFACTURING OPERATION[a,11]

Operation	Total fibers	Fibers >5 μm
Asbestos textiles		
Fiber preparation and carding	2.0	2.1
Spinning, twisting, and weaving	1.8	1.9
Asbestos friction products		
Mixing	1.1	1.1
Grinding, cutting, and drilling	1.0	1.1
Asbestos-cement pipe		
Mixing	1.2	1.2
Finishing	1.6	1.8
Asbestos insulation		
Mixing	1.0	1.1
Finishing	1.8	2.0

[a]Fiber counts made at 970x and 430x magnification with phase-contrast illumination.

Table 2-6. FIBER SIZE DISTRIBUTIONS BY MANUFACTURING OPERATION[a,11]

Operation	Fiber median length, μm	Percentage >5 μm
Asbestos textiles		
Fiber preparation and carding	1.4	4
Spinning, twisting, and weaving	1.0	2
Asbestos friction products		
Mixing	0.9	2
Grinding, cutting, and drilling	0.8	2
Asbestos-cement pipe		
Mixing	0.9	2
Finishing	0.7	1

[a]Fiber counts made with a 5000X electron microscope.

the total numbers of fibers present. The areal density of fibers collected on a membrane filter for electron microscope analysis is preferably much larger than that appropriate for light microscopy; otherwise, the counting of a large number of fields selected by an appropriately random method is required. Of particular significance is the properly weighted inclusion of large groups of fibers approximately 0.1 μm in diameter by 1.0 μm in length, which are occasionally observed; these fibers may be present in emissions as coherent collections of fibers rather than having resulted from the deposition of many single fibers onto a sampling filter.[11]

Good agreement has been observed between fiber counts obtained by light microscopy and those determined by electron microscopy for relatively long fibers. The primary discrepancy between the methods appears in the counting of fibers shorter than 1 μm.[11] Electron microscopic fiber- or particle-counting techniques are yet to be standardized, but some procedures that overcome many of the problems, such as identification of asbestos fibers from among a collection of other inorganic and organic particulates collected simultaneously with the asbestos, have been developed.

Characteristics of asbestos emissions that might prove to be relevant in the study of adverse health effects are:

1. Type of asbestos.

2. Distribution of length-to-diameter ratio for fibers of various lengths.

3. Contamination of fibers with inorganic and organic materials from ores or from mining, milling, processing, shipping, and usage.

4. Contamination of fibers with inorganic and organic substances present in the atmosphere or in the respiratory tract.

In view of the present uncertainty as to which parameters of asbestos emissions are most significant, biologically, it appears advisable to provide characterizations as complete as present technology permits; and the development of new technology that would extend the range of description is warranted. Future developments may permit the limitation of these tasks. For example, it has been suggested that the total fiber counts obtained by electron microscopy are not necessarily more appropriate indicators of asbestos exposure than are total counts determined by 430X magnification.[11] As a second example, it may be possible to develop rather detailed, standardized specifications of emissions from classes of emission sources and to subsequently monitor only the most significant parameters of these descriptions to determine emission levels.

2.5 MAJOR SOURCES OF ASBESTOS EMISSIONS

Asbestos as it exists in a natural state, for example as veins of chrysotile embedded frequently mechanically bound in such a manner that the thin fibers that contribute to air pollution are not readily emitted. Exceptions to this natural constraint are found in the chrysotile ores of Fresno and San Benito counties in California where high-concentration ores of loosely bound, short-fiber asbestos are exposed to the atmosphere and also in the soil of farm lands in Bulgaria that contain anthophyllite.[11] Airborne asbestos emissions result from the mining of asbestos ores, the milling of asbestos ores to exploit the property by which asbestos can readily be separated into an extremely fine fibrous material, and the manufacture and use of numerous asbestos-containing materials.

No data base of asbestos ambient air concentrations for the United States exists; however, preliminary data, which are accurate to within a factor of 2 or 3, indicate asbestos concentrations ranging from 11×10^{-9} to 60×10^{-9} grams per cubic meter (g/m^3) in New York City.[13]

The role of asbestos in air pollution differs significantly from that of many other pollutants, such as nitrogen oxides and some elemental metallic particulates, in that it does not enter into a natural cycle of organic growth. Rather, asbestos precipitated from the atmosphere is extremely stable with respect to chemical decomposition and is subject to reentrainment into the atmosphere.

Engineering appraisals based primarily on visual inspection of a limited number of facilities, estimates of typical particulate collection efficiencies for currently installed control equipment, and typical percentages of asbestos in the material from which the particulate originated have been used to estimate the *relative percentages* (on a mass basis) of asbestos emissions from stationary sources in the United States.[14] More data are necessary in order to determine absolute total mass emis-related, fiber count emission rates.

Asbestos mines and mills are estimated to contribute 85 percent of the total emissions of asbestos from stationary sources.[14] Of these emissions, over 90 percent are from asbestos mill operations, which include the crushing, drying, and concentrating of asbestos ore and the disposal of tailings.[14] Typically, emissions from crushing operations are uncontrolled, and emissions from drying operations are controlled only by centrifugal collectors. Most mills attain some degree of emission control by using either centrifugal collectors or centrifugal collectors in combination with fabric-filter collectors to clean process air streams. The potential for emissions from wet-process milling is much less than the emission potential of typical dry milling operations.

Air ventilation systems that exhaust to air cleaning devices are frequently used to control emissions from processes incorporated in the manufacture of asbestos-containing products. These partially controlled emissions are estimated to account for 10 percent of the total of all asbestos emissions.[14] The manufacture of friction materials, asbestos-cement products, vinyl-asbestos tile, asbestos textiles, and asbestos paper represents the source of over 90 percent of the emissions from manufacturing processes.[14] The sum of the emissions from numerous miscellaneous manufacturing processes, such as the production of calcium silicate-asbestos fiber pipe insulation, asbestos-asphalt coatings, asbestos-containing paints and coatings, and various asbestos-reinforced plastic products is also significant and is estimated to be of the same magnitude as the sum of emissions from the manufacture of both asbestos textiles and asbestos paper.[14] In each case, the emissions are principally from the mixing and handling of the dry fiber; thus, emissions can be significantly reduced by the addition of more efficient control of handling and mixing operations.

The major sources of asbestos emissions from the end-uses of asbestos-containing materials include the grinding and fitting of replacement brake linings; the spray application of asbestos-containing fire proofing; the erosion of the interior insulating linings of boiler breechings, ducts, and economizers; the installation of asbestos-containing pipe insulation; and the cutting of asbestos-containing siding, wallboard, shingles, and other construction materials. The end-uses of asbestos-containing products are estimated to account for 5 percent of total asbestos emissions.[14] In many cases, such as the grinding and fitting of replacement brake linings, emissions are controlled by fabric filters that collect more than 96 percent of the particulate emissions; such partially controlled emissions represent approximately 50 percent of the emissions attributed to end-uses.[14] Emissions to the atmosphere from the abrasion of vehicle brake linings during usage and from demolition operations are not included. Although emissions from the spray application of asbestos-containing fireproofing are estimated to be only slightly more than 1 percent of total asbestos emissions, these emissions are very significant because they occur in densely populated areas.[14]

Emissions from the use of an asbestos precoat as a filter aid for certain fabric dust filters applied to streams with low particulate loadings are considered negligible because of the small number of such applications and the extremely long periods (often 2 or 3 years) between applying the precoat and cleaning the filter.

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3. ASBESTOS EMISSION SOURCES, CONTROL TECHNIQUES, AND CONTROL COSTS

3.1 MINING OF ASBESTOS ORES

Chrysotile, which is the fibrous form of serpentine, and crocidolite, amosite, anthophyllite, tremolite, and actinolite, which are fibruous forms of the amphibole minerals, usually occur in veins embedded in massive rock deposits. The three fiber types are cross, slip, or bulk. None of the asbestoses is characterized by a single type of fiber; however, chrysotile and crocidolite occur predominantly in the cross fiber.[1] Anthophyllite occurs in all three forms.[1] The concentration of asbestos in commercial ores is as large as 60 percent in California's short-fiber Coalinga ores, but the largest deposits of longer fiber chrysotile contain from 4 to 10 percent asbestos. After extraction from the ore, typically only 3 to 25 percent of the asbestos is of sufficient length for use in spinning applications.[1] None of the California chrysotile fiber mined in Fresno and San Benito counties, however, is suitable for spinning.

When deposits of asbestos occur near the surface of the earth and are not bound within massive rock deposits, surface mining methods are employed; the shallow overburden and the ore are removed by power shovel and bulldozer or by other scraper-type vehicles. Those California deposits noted above are mined by this technique. The North Carolina deposits are also worked, on a small scale, by surface mining. The open-pit mining of some ore deposits, such as those in Vermont that extend both laterally and to a considerable depth below ground level, requires extensive blasting to loosen the overburden and ore for removal. The mining proceeds along either parallel or spiral amphitheater-like terraces, which extend to the floor of the pit. Where narrow bands of asbestos veins extend far below the surface, as in Arizona, it is necessary to resort to underground mining in which shafts that follow the deposits are opened. In addition, open-pit and underground mining are sometimes applied concurrently, as in the Quebec mines. In these cases, galleries or shafts are initiated from the base of the pit, the pit wall, or a mountain slope.

The transformation of asbestos deposits into ores suitable for processing by an asbestos mill involves any or all of the following operations: (1) drilling to place explosive charges, (2) primary and secondary blasting, (3) surface scraping, (4) sorting, (5) screening, (6) conveying, (7) shoveling, (8) transporting by truck, and (9) dumping.

3.1.1 Emissions

Each of the processes associated with asbestos mining that are listed above is a potential source of asbestos emissions. Local meteorological conditions can significantly influence the degree of emission. For example, rain, sleet, and snow are favorable influences because they result in wetting or covering exposed ore deposits in addition to scavenging the atmosphere. Conversely, strong winds that are capable of widely distributing existing emissions, in addition to entraining loosely bound asbestos fibers from material exposed to the atmosphere by mining operations, are an adverse influence. Furthermore, the natural phenomena of earth movement, temperature cycling, wind erosion, and water erosion present opportunities for the emission of asbestos from virgin surface-ore deposits.

In those surface mining operations that require blasting, the use of rotary or percussion drilling machines that incorporate air-flushing is a potential source of appreciable amounts of dust emissions.[2] Air-flushing refers to the use of an air stream, operated by pressure, vacuum, or pressure and vacuum in combination, to cool the drill bit and lift cuttings out of the hole formed for placement of explosive charges. Air travels down the hollow center of the drill bit as the drill cuttings move upward along the outside of the bit. Smaller dry suction drills employ an injector to exhaust air from a hood or cowl that encloses the drill bit at the hole collar. Even in a wet-drilling process, in which compressed air and water are injected in the downward-flow mode, a portion of the dust generated by drilling escapes without being converted into sludge. Further, a respirable aerosol of water droplets having entrained drilling dust can be emitted.[2]

Detonation of explosive charges in the open-pit mining of various minerals breaks up massive deposits of asbestos-bearing rock, and the blast can produce a cloud of dust that may contain asbestos fibers. Similar emissions can occur when secondary blasting is used to reduce boulders to a size acceptable by the mill or to dislodge large rock deposits in open-cast mining.

In surface mining, the operations of removing overburden, scraping and shoveling of ore, preliminary screening of ore, conveying of ore, loading of ore into trucks, and the unloading of ore from trucks into hoppers at the mill can generate emissions of asbestos dust. Some ores have a high moisture content (as much as 20 percent in Fresno and San Benito counties), and, therefore, emissions from processing these ores are less than those encountered with dry ores. The emission sources associated with underground mining installations include sorting, conveying, loading, and unloading operations, which are performed outside the mines. The exhaust of ventilation air from underground mines to the atmosphere can also produce emissions.[3]

The transit of ore-loaded trucks over distances of perhaps hundreds of miles between a mine and the processing mill represents another potential emission source. If the moisture content of ore hauled in open-truck bodies or of the unsealed surface of roads constructed of asbestos-containing overburden or mill tailings is low, asbestos dust can be entrained by the atmosphere as the ore load is jostled and the road surface is abraded.

3.1.2 Control Techniques

Overall emissions from asbestos mining facilities are not stringently controlled at present. The absence of a higher degree of control is traceable to the fact that most operations are completely exposed to the atmosphere, with the result that emissions are diluted with ambient air over relatively large surface areas such as mining pits and roads.

Both dry centrifugal dust collectors and fabric filters have been applied to allay the dust generated during air-flushed drilling of holes for explosive charges.[2,4,5] It is well known that the collection efficiency of fabric filters, expressed on a total mass basis, exceeds that of conventional cyclone collectors.[6] In Figure 3-1, the application of a fabric filter of envelope type to a primary percussion drilling machine employed in asbestos mining is illustrated.[4] Several treated synthetic filter materials, such as Rayon* acetate and Nylon* acetate treated with silicate, have been shown to release dust loadings readily during the cleaning cycle and to dry quickly if accidentally wetted in use. Air flow rates of several typical drilling machines are shown in Table 3-1.[4]

The use of wet drilling methods to control emissions has been excluded from

*Mention of a specific product or company name does not constitute endorsement by the Environmental Protection Agency.

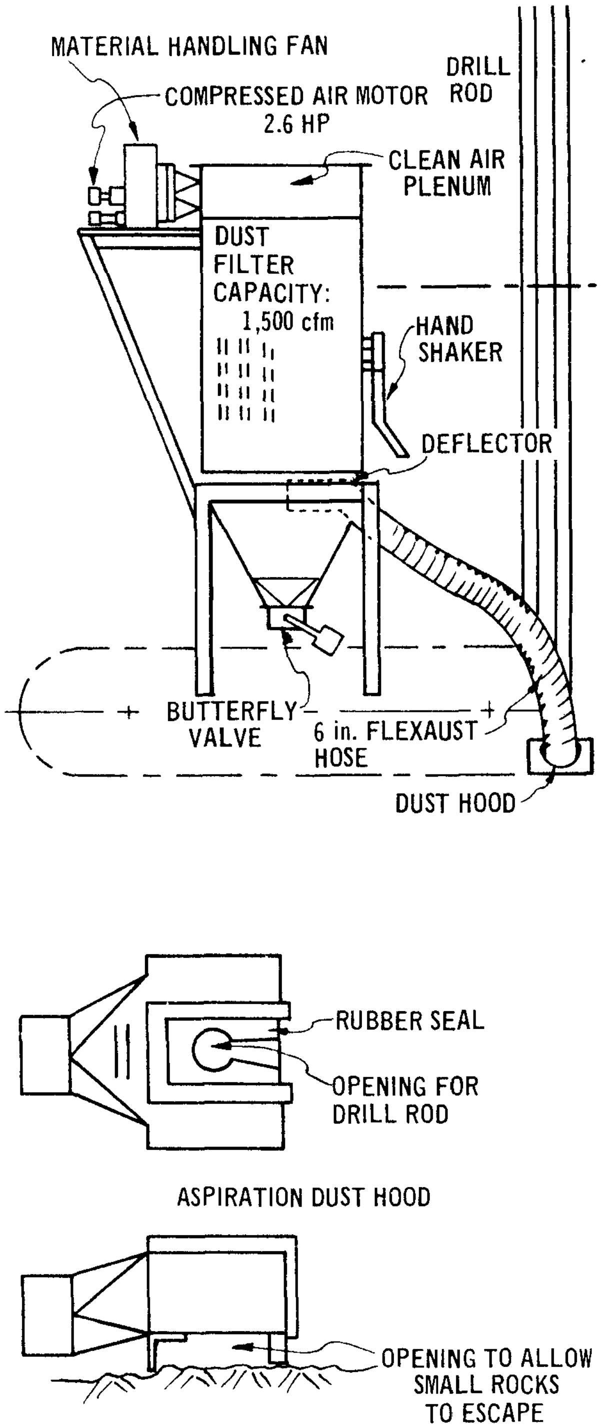


Figure 3-1. Fabric filter mounted to drilling machine.[4]

some asbestos mining operations because of extremely cold climates or restrictions imposed by water pollution control regulations. Other types of surface mining operations have overcome prohibitively cold weather by heating water on the drilling machine and insulating the water storage tank and all exposed piping.[2] Even heated water, however, can freeze after discharge from the drill hole. Since primary drill holes are often located within 10 feet of the edge of a bench, which may range from 30 to 75 feet in height in asbestos quarries, the presence of ice can pose a serious occupational hazard. In warmer climates, the tendency of the drill cuttings to cement together as water seeps into asbestos seams in the fractured rock is an operational problem that limits the effectiveness of wet drilling. In the case of wet drills smaller than those used for primary drilling, the inclusion of special design features, such as front-head release ports for the venting of compressed air or an external water feed mechanism, can control the emission of unwetted dust or respirable water-dust aerosols.

The atmospheric emissions that result from primary and secondary blasting in asbestos surface mining are essentially uncontrolled at present.[7] An optimum combination of amount, depth, and location of explosive charge should be sought that will produce complete combustion of the explosive compounds, along with the required loosening and breaking of a deposit, without unnecessary expulsion of material into the air. Multi-delay devices for the initiation of detonation have been used successfully at limestone quarries,[6] but incomplete combustion of multi-delay charges, resulting from the highly fractured nature of the ore, has been observed at one domestic asbestos mine. Detailed technical assistance in implementing good blasting practice is available from explosives manufacturers.[5]

The spraying of water or chemical wetting agents onto a surface prior to blasting could reduce emissions. The application of a

Table 3-1. AIR FLOW RATES OF TYPICAL DRILLING MACHINES[4]

Type of machine	Hole diameter, in.	Filter capacity, ft^3/min	Fan drive
Percussion drill, air	4	1500	Air (90 psi)
Rotary drill, diesel	6¾	2000	Hydraulic
Rotary drill, electric	6¾	3000	Electric
Secondary drill, diesel	2½	500	Air (90 psi)

pressurized water spray to asbestos mining would not be novel; the cleaning of deposits subsequent to the removal of overburden has been accomplished by high-pressure water sprays.[8] The surface area of the blasted fragments, however, is so large in comparison with the surface area prior to blasting that the effect of surface wetting alone is likely to be minimal.

The use of liquid or paste stemming materials in blasting holes is a promising dust control method.[2] In European coal mines, reductions of 20 to 80 percent in dust concentrations have resulted from placing plastic cartridges filled with water, or water in combination with a wetting agent, into holes betore blasting. This technique has also been tested in copper mining operations.[2] As an alternative to the use of liquid-containing cartridges, pastes with a cellulose or bentonite base can be employed.[2] Container materials and wetting agents that would not interfere with the required purity of the milled asbestos should be developed.

Effective primary blasting minimizes the need for secondary blasting and is, therefore, an indirect method of controlling emissions from secondary blasting. The use of drop-ball cranes and pneumatic or hydraulic rock splitters as substitutes for secondary blasting has proved to be effective in controlling emissions from limestone quarrying,[5] however, the extent to which the elasticity of asbestos-bearing rock might limit the effectiveness of drop-ball cranes for secondary fragmentation has not been fully evaluated.

The removal of overburden from ore deposits, shoveling of loosened ore, surface scraping of ore, preliminary screening and conveying of ore at the mine, and loading of ore into trucks produce asbestos emissions that are substantially uncontrolled at present. These operations, as well as primary and secondary blasting, should be scheduled to coincide to the maximum extent practicable with meteorological conditions favorable to the suppression of atmospheric emissions. In particular, cognizance should be taken of seasonal variations in weather conditions. The limiting of operations to periods of favorable weather conditions may occasionally be impractical because of the large amount of equipment involved and because of safety precautions requiring that blasting be carried out on the same day that the charge is loaded. The application of water or chemical sprays can alleviate emissions from ore loading in some cases. Limiting factors are the possible freezing of the water or the introduction of chemicals that would interfere with the end use of the asbestos.

The atmospheric entrainment of asbestos dust emitted from loads of ore in transit from mine to processing mill can be controlled by transporting the ore in a closed-body vehicle or by fitting a flexible, impervious cover over the exposed ore load. Where roadways connecting mine and mill have been surfaced with asbestos mill tailings, emissions can be reduced by periodic spraying of the roadways by water trucks.[4] Care must be taken, however, to ensure that hazardous driving conditions are not created. Tests have shown that the application of lignin sulfonate to roadways at mining facilities reduces markedly the emission of dust caused by vehicular traffic;[9] a solution of 10 to 25 percent solid lignin in water has given the best results. More recently, the application of emulsified asphalt to roads servicing open-pit mines has provided even greater emission reduction than the use of lignin sulfonate.[10] In the planning of mining and milling operations, the possibility should be examined of reducing roadway emissions through minimizing the number of vehicle-miles by using trucks of maximum practicable capacity and by reducing the distances between mines and mills. The operating speed of vehicles is an important parameter that can affect emissions from unpaved roadways.

Asbestos emissions that result from the dumping of ore from trucks at the mill site can be abated by the use of water sprays or by the application of capture hoods or enclosures combined with gas-cleaning devices. Some domestic mills currently use partial enclosure and water spraying techniques.

Attempts have been made to stabilize mine overburden dumps where the waste rock, sand, and clays of hard-rock asbestos deposits are chemically neutral.[4] These efforts have been successful to the extent that grasses and trees have been established over the surface of some waste dumps. Most areas exposed by open-pit mining, other than steep slopes, can probably be revegetated.

3.2 MILLING OF ASBESTOS ORES

Separation of asbestos fibers from accompanying masses of rock typically is initiated by conveying mine ore, via a large hopper and pan feeder, to a primary crusher.[8] In some instances, larger bodies of crude asbestos fibers, freed from massive rock deposits, are removed by hand sorting at the mine. In typical commercial practice, a primary, jaw-type crusher then accepts boulders of up to 48 inches in "diameter" and reduces these to fragments with "diameters" not larger than 6 inches. Subsequently, this crushed rock is transported by belt conveyor to trommel screens, which are rotating cylinders with openings of various sizes, or to a stationary-bar grizzly, a type of screen, for the sizing operation. Ore fragments of greater than 1-1/4-inch "diameter" are routed to a secondary cone-type crusher for further reduction in size, and the outputs of primary and secondary crushers are conveyed to a wet-ore storage pile exterior to the mill. This stockpile usually contains a sufficient quantity of ore to sustain mill operation for an extended period of time. The above sequence of operations is illustrated in Figure 3-2.

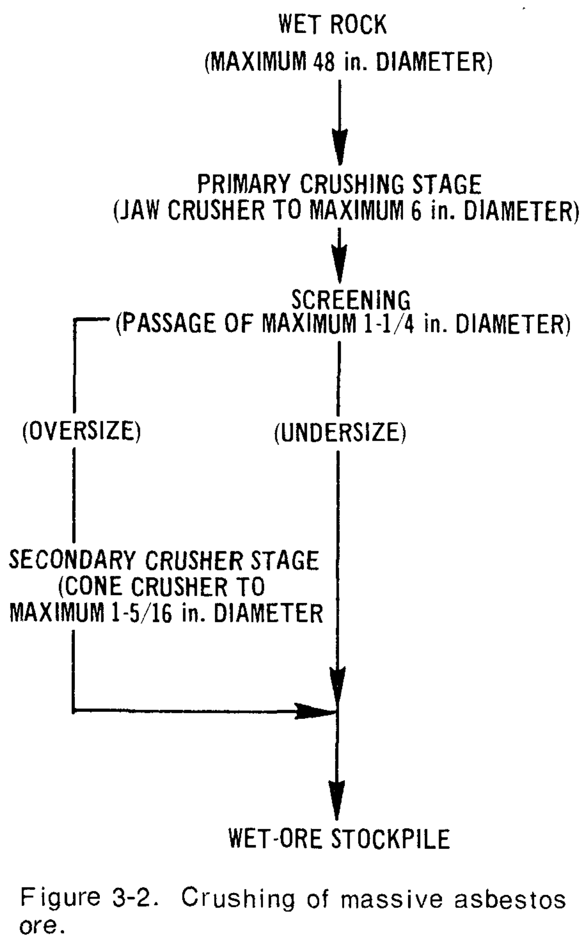


Figure 3-2. Crushing of massive asbestos ore.

The Coalinga deposit of asbestos ore in California presents an exception to the above practices in that no primary crushing is carried out prior to drying of the ore. Typically, trucks dump mine ore adjacent to a mill to form a wet-ore stockpile, which is exposed to the atmosphere.

In larger milling operations, wet ore is extracted from the bottom of the wet-ore stockpile by a vibrating-chute feeder located in an underground tunnel. As indicated in Figure 3-3, which illustrates a specific facility in operation, the larger fragments of the ore being conveyed upward to a stationary-rod screen can be routed to bypass the dryers if the moisture content of the fragments is sufficiently low. The wet ore enters cylindrical dryers that slowly rotate to permit baffles internal to the dryers to pick up and release the wet ore continually and thereby thoroughly expose it to a drying current of hot air. This air, heated in a firebox at one end of the dryers, is forced co-currently through the dryers in the axial direction. Ore is heated typically to 110°F, and a downward inclination of about 4 degrees fixes the residence time of the ore in the dryers at approximately 15 minutes.[8]

As illustrated in Figure 3-3, the dried ore is conveyed by belt to a vibrating screen that sizes the ore for fine crushing. Ore of more than 1-3/8 inches in "diameter" is sent to a cone crusher connected in a closed circuit with the screen, whereas the ore of particles larger than 5/8 inch and smaller than 1-3/8 inch is diverted to cone crushers that produce material of approximately 1/4-inch "diameter." The undersized screenings and the output of the latter crushers form a dry-rock stockpile, which is housed so that it is protected from the exterior environment.[8]

The finely crushed, dried asbestos ore next traverses a rock circuit. The principal purpose of this set of operations is to separate asbestos fibers from the coexisting rock, but the circuit secondarily functions to grade fibers according to length. The oversized material from the first vibrating screen shown in Figure 3-3 passes to fiberizers that further disintegrate the rock and release additional fibers. Undersized material from this same screen is routed to shaker screens of finer mesh; these screens are equipped with air suction (aspiration) hoods that facilitate the entrainment of asbestos fibers in an air stream and thereby separate them from the surrounding rock. This air flow conveys the asbestos to fiber-cleaning circuits. The continuation of the process is accompanied by additional screenings, air aspiration to remove freed asbestos fibers, and further rock disintegration in an impact mill.[8]

In the rock circuit, cleaned rock is finally expelled to an exterior tailings dump. As the air streams that convey aspirated asbestos fibers are passed through cyclone collectors, the fibers are removed for cleaning and for additional grading. Exhausts from these collectors are ventilated to gas cleaning devices. At this step of the process, the asbestos fibers have been graded according to long, medium, and short lengths.[8]

It is intended that the fiber-cleaning circuits perform additional fiber opening, classify and separate opened fibers from rock and unopened material, and carry out further fiber-length grading. Initially the fibers pass through graders constructed of perforated plates in which rotating beater arms further open the material. Undersized fractions are added to short fibers from the rock circuit, and the oversized material undergoes aspiration on shaker screens to transfer the fiber to the grading circuit. Various other stages of screening, aspirating, and opening are involved in this circuit; in addition, some material is rejected as waste. The aspirated asbestos fibers are deposited into cyclone collectors and subsequently delivered to the grading circuit as long, medium, short, and extra short fibers. As in the case of the rock circuit, the exhausts of the cyclones are directed to a gas-cleaning device.[8]

The separation of asbestos fibers into numerous standard grades, in addition to further fiber cleaning, is accomplished in the

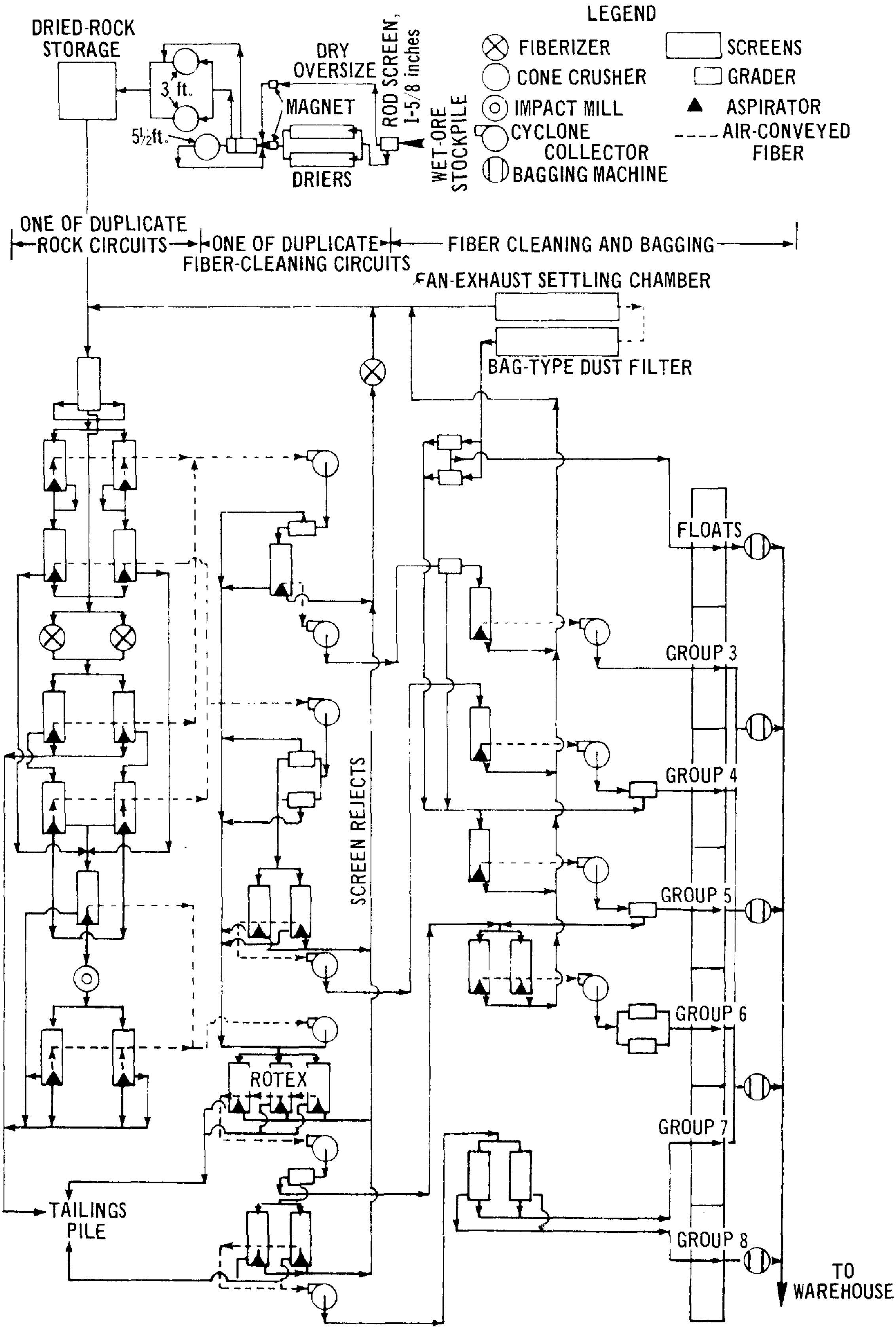


Figure 3-3. Flow sheet of an asbestos milling process.[8]

grading circuit shown in Figure 3-3. Standard grading machines effect additional opening of fibers and facilitate the removal of shorter fibers. The process of air aspiration from vibrating screens separates out additional fine dust, fine rock fragments, and unopened fibers. To control asbestos-containing dusts, the cyclone collectors are exhausted through fabric filters.

Asbestos fibers are machine packaged either by compressing the material into a dense bundle or by blowing the material into a container. The longest fiber grades are loosely packed to minimize damage to the fibers and to eliminate the subsequent necessity for excessive willowing of compressed material. Valved, multi-ply paper bags are commonly used to package the shortest fibers.[8]

One domestic asbestos mill, which processes short-fiber Coalinga ore, employs a wet process.[11] An ore-water mixture is carried through a proprietary grinding and separating process to mill the asbestos almost entirely into fibrils; a subsequent dewatering operation produces pellets of asbestos fibers. The cylindrical pellets measure approximately 3/8 inch in diameter by as much as 3/4 inch in length and are formed and subsequently dried without a binder. Some of the asbestos is marketed in pellet form to end users. If a completely opened form of asbestos is needed for a manufacturing process, the dry pellets can be ground either at the mill or by the end user.

3.2.1 Emissions

The milling of asbestos ore by a dry process requires an extensive amount of handling and subdividing of the material in both a damp and a dry state. Consequently, there are numerous potential sources of asbestos emissions at a milling facility.

The dumping of mine ore from trucks onto a wet-ore stockpile or into receiving hoppers is a potential emission source at the mill site (previously noted in Section 3.1.2). Further, asbestos-containing dust at the surface of an ore pile is susceptible to varying degrees of atmospheric entrainment, depending upon the moisture content of the ore and the strength of local winds.

The separating, cleaning, and grading of asbestos fibers requires large volumes of air, which are ventilated through fabric filters before being exhausted to the atmosphere or recirculated to mill buildings. Because makeup air is drawn in to replace the exhausted air, process areas of a mill are frequently under negative pressure. When the volume of air exhausted to the atmosphere is sufficient for the entire mill to be under negative pressure, emissions to the atmosphere are reduced.

As asbestos ore, asbestos fibers, and asbestos-containing tailings are transported among the numerous processing devices of the mill by belt conveyors, the jostling motion, combined with the large surface area of material exposed to the environment, can produce significant asbestos emissions either directly into the exterior atmosphere or into the surrounding work space. Examples of such emission sources are transportation of material from a wet-ore stockpile to a dryer, from a dryer to a grading screen, from one vibrating air aspiration screen to another, and from the undersized side of a vibrating air aspiration screen to a tailings conveyor. The potential for particularly severe emissions exists whenever asbestos-containing materials are handled at the transfer points of conveyor systems.

The severe fracturing of rock by primary and secondary crushers frees additional asbestos fibers from the ores; the accompanying mixing action of the crushers facilitates the emission of asbestos-containing dusts to the interior spaces of the equipment. Because feed and discharge ports must be provided for crushers, an opportunity exists for the emission of asbestos to the exterior environment.

A primary source of emissions from asbestos mills is the effluent from ore dryers.[4,12] The mechanical agitating action of the dryer and the necessity for contacting the ore with large volumes of air contribute to the entrainment of asbestos-containing dust in the heated gas stream. In addition to contaminants from the ore, the dryer exhaust contains a significant amount of moisture and the products of combustion from the air-heating device. The effluent temperature varies widely and can range from 140°F to 500°F.[4]

The vibratory or oscillating motion of grading screens and the resulting sifting action of the screens as the asbestos-containing material is separated into a range of sizes expose large surface areas of material to the surrounding air; the surface of a typical screen measures 5 feet by 11 feet.[8] Accordingly, this process results in appreciable quantities of airborne dust. If there are no provisions for capturing and containing the dust, it is emitted directly into the mill work space.

Even though the packaging of asbestos fibers by machine minimizes handling and exposure of the material to the atmosphere, emissions can occur at the interface between the material and the package during the filling and sealing of containers. The packaging of fibers into coarsely woven bags[8] or otherwise non-dust-tight containers can yield emissions during further handling operations. The potential emissions associated with those operations, which range from packaging to shipping of asbestos, are discussed in Section 3.3.1.

Large quantities of dry, finely divided rock that contain asbestos dust must be removed from most asbestos mills as waste material. The transfer of this rock by a moving-belt device or by vehicle to an exposed tailings dump can generate emissions to the atmosphere. Emissions can also result from the placement of tailings onto an existing dumps, from the leveling of the dump to permit further deposition of wastes, and from direct entrainment of surface dust by ambient air currents.

3.2.2 Control Techniques

To control asbestos emissions from the surface dusting of ore stockpiles, water can be sprayed onto the material from adjacent towers. This technique has also been successfully applied in the control of particulate emissions from exposed limestone stockpiles.[5,13] In a typical limestone application, water is sprayed at a rate of 500 gallons per minute from towers 40 feet high: the spray covers a circle 200 feet in radius.[13] For asbestos applications, it may be necessary to use the lowest feasible flow rates in order to avoid the discharge of asbestos-containing water from the facility and to comply with applicable water pollution control regulations.

It is technically feasible to house exterior belt and bucket conveyor systems in completely enclosed galleries to prevent asbestos emissions from material in transit and from the emptied return side of the systems. Furthermore, the attainment of safe occupational asbestos exposure levels may require the enclosure of in-plant conveyor systems. The asbestos milling industry is currently applying these control techniques to a limited extent.[4] Points at which asbestos ore, asbestos fiber, and asbestos-containing waste materials are transferred between process equipment and conveyor systems, as well as conveyor system transfer points, can be hooded and ventilated to gas-cleaning devices to control emissions.[4] A schematic diagram of this technique, as applied to the transport of asbestos ore from a crusher to a storage bin, is shown in Figure 3-4.

The feed and discharge ports of ore crushers can be fitted with dust capture hoods to control asbestos emissions; the hoods should be ventilated to a gas cleaning device such as a fabric filter. Figure 3-5 illustrates a device of this type, having an air flow capacity of 3000 cubic feet per minute, attached to the inlet of a 48-inch by 60-inch jaw crusher.[4] A hinged suspension permits convenient displacement of the hood to provide access in cleaning ore blockages from the crusher.

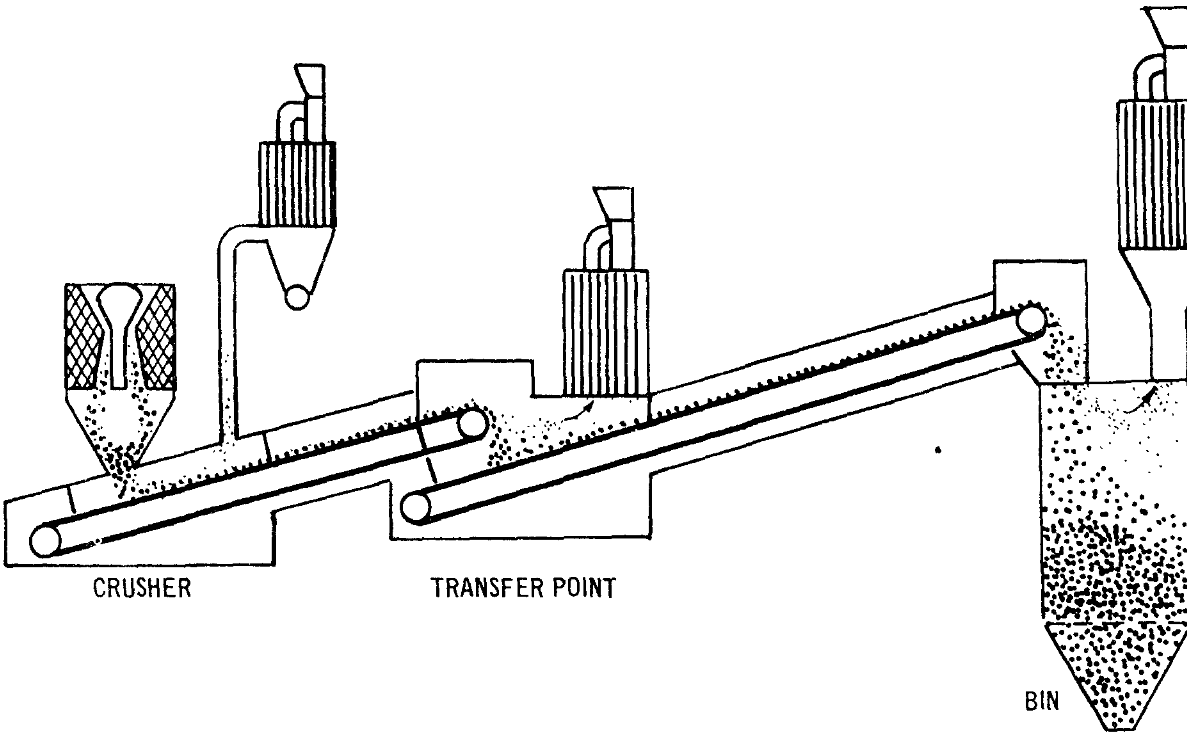


Figure 3-4. Control of emissions from transport of ore.[4] (Conveyors not shown enclosed in Reference 4)

Historically, cyclone collectors have been applied more widely than any other type of gas-cleaning device to control asbestos emissions from ore dryers, largely because of the relatively low initial cost, simplicity of construction, and low maintenance cost of these devices. Also, the dust collection efficiency of cyclones is relatively insensitive to variations in process gas temperature and to the condensation of moisture within the collector; however, the fact that the efficiency of these dry centrifugal collectors is considerably less than that attainable with some other widely employed gas-cleaning devices has prompted attempts to gain increased collection efficiency. For example, one milling facility has employed 200 small-diameter cyclones, each with a capacity of 100 cubic feet per minute, as a substitute for a single cyclone of 20,000 cubic feet per minute air-handling capacity.[4] Partial plugging of the small collector elements occurred, possibly as a result of internal water condensation, with the result that collection efficiency was greatly decreased, rather than increased. As a compromise between the commonly applied 10-foot-diameter cyclones and the potentially more efficient small-diameter devices, twin cyclones 4 feet in diameter were chosen. In recognition of the relatively low efficiency of cyclones for the collection of finer particulates, the Canadian asbestos industry is seeking control techniques that exceed the performance of dry centrifugal collectors.[4]

Wet collectors are presently employed by the Canadian asbestos industry on at least two ore-drying installations; the process gas flow rates are 100,000 and 65,000 cubic feet per minute.[4] In these two collectors, the particulate-laden gas stream passes through a water spray and then enters into a centrifugal fan that dynamically separates dust and particulate water from the stream as air is drawn through the blades; the asbestos-containing particulates are removed as a slurry. Corrosion resulting from sulfur oxides present in the dryer effluent,[4] and the limited collection efficiencies of 85 to 95 percent are significant disadvantages of these wet collection devices.

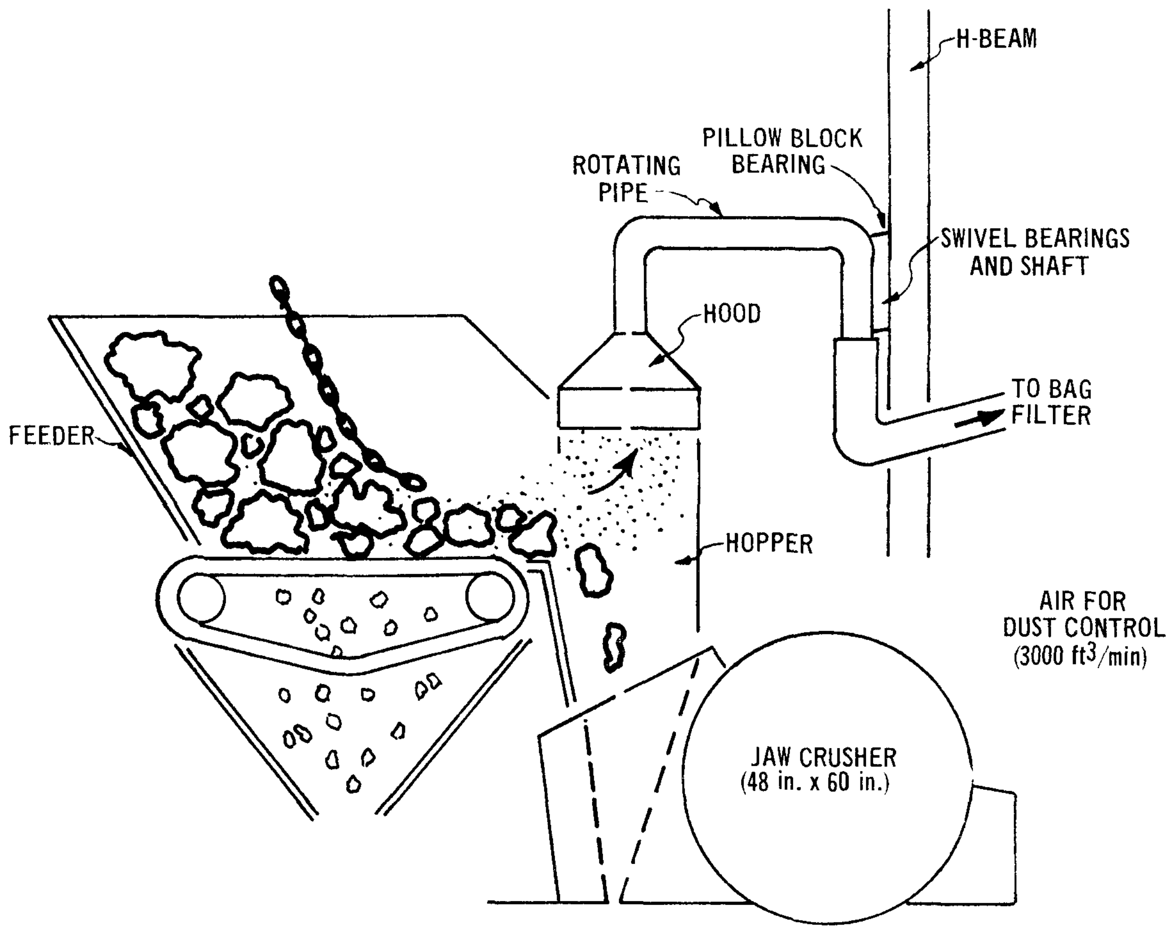
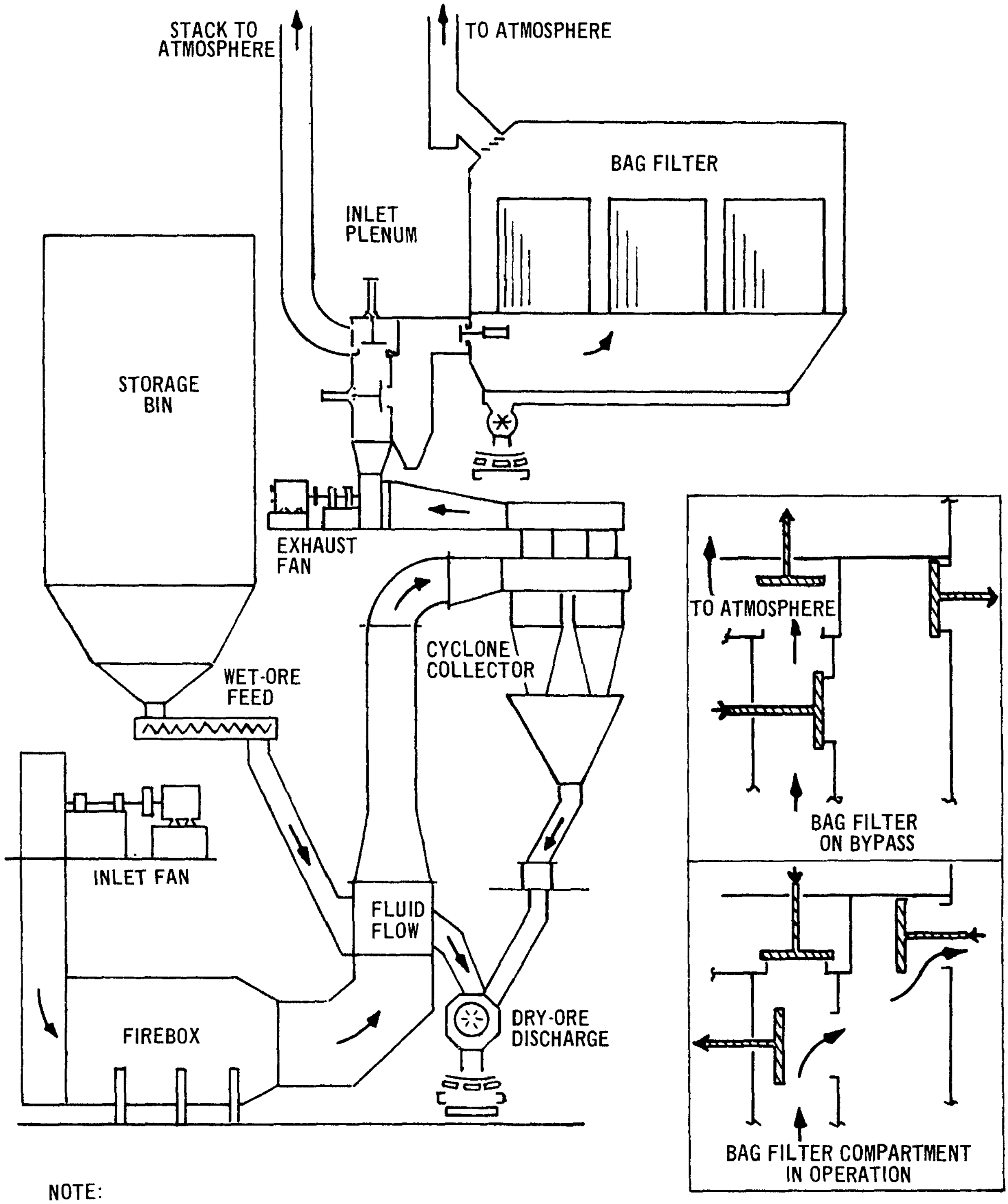


Figure 3-5. Dust capture hood fitted to ore crusher.[4]

In spite of low pressure loss and the theoretically high collection efficiencies, electrostatic precipitators are not widely applied to the control of asbestos emissions from ore dryers. This is a consequence of the necessity for maintaining close control of gas velocity, gas temperature, and particulate moisture content in order to realize design collection efficiency. An electrostatic precipitator of 170,000 cubic-feet-per-minute capacity is now in operation at a Canadian asbestos mill.[4]

Fabric filters have been successfully applied to the control of emissions from asbestos ore dryers,[4,12] and it is reported that asbestos emission levels of approximately 2 x 10^6 particles per cubic foot (ppcf) have been realized.[4] Two new units were scheduled to be placed into operation in Canada in 1971; Figure 3-6 shows an asbestos ore dryer of the fluidized-bed type and accompanying bag filter installation that are to be installed at a Canadian mill in 1972.[4] The filtering chambers of these baghouses are thermally insulated to prevent excessive cooling of the effluent gas streams and the possible condensation of water; the occurrence of condensation could irreversibly cement adhering dust cakes. Orlon, Dacron, Nomex, Teflon, Terylene, or Fiberglas, which can withstand the high temperatures of the gas streams, are required as filter materials. Additional protection against excessively high temperatures or condensation of moisture during short time periods can be provided by the use of by-pass arrangements. For effective



NOTE:

BAG COLLECTOR
14 COMPARTMENTS. 50,000 cfm EACH
OPERATING TEMPERATURE RANGE 170°F TO 250°F
BAGS OF SPUN ACRYLIC CLOTH

DRYERS
3/4 in. MATERIAL DRIED FROM 10% TO 2% MOISTURE.
150 TONS/HOUR.

Figure 3-6. Configuration of fabric dust collector for ore dryer.[4]

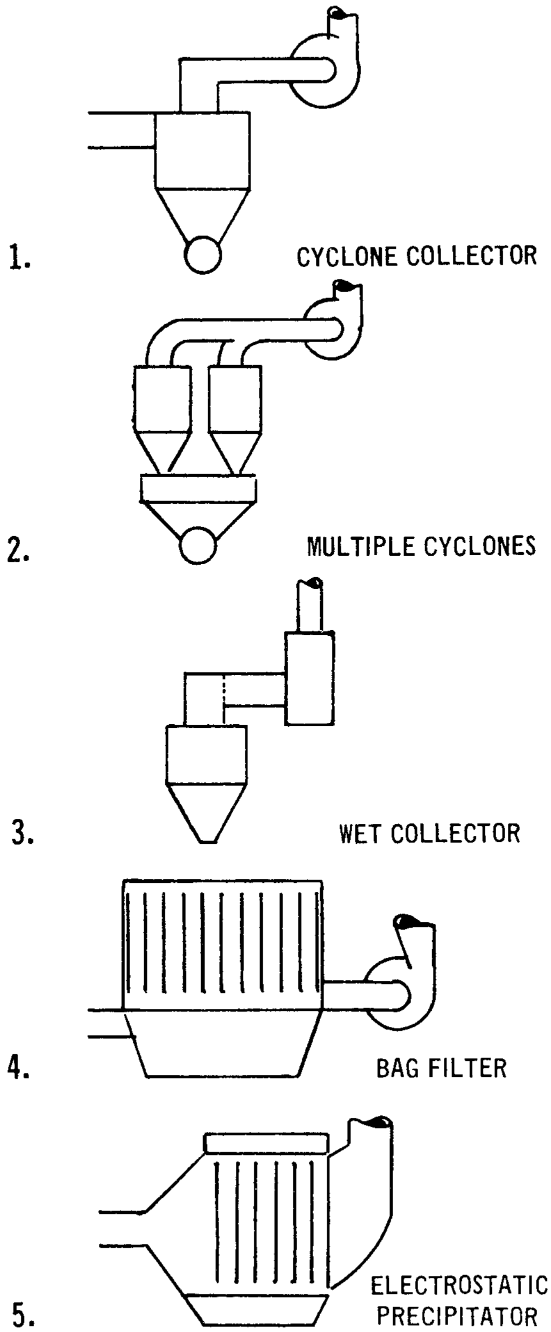
control of asbestos emissions, engineering design and operational procedures should minimize the duration and number of periods in which bypass devices are utilized.

Figure 3-7 provides relative comparisons of asbestos-containing dust emissions from ore dryers subsequent to cleaning of the effluent stream by one of five control devices.[4] These calculated estimates of emissions are based upon operating experience of the Quebec asbestos milling industry. The emission rates are based upon an assumed value of 1 pound per hour for fabric filter collectors.

Asbestos emissions from the bed of a vibrating grading screen can be controlled by covering the screen, with a dust capture hood, as completely as practicable without interfering with the required screen motion. Figure 3-8 shows a group of enclosed screens; the hood exhaust streams are passed through a fabric filter to remove the entrained dust after asbestos fiber has been deposited in cyclone-type collectors. Quantitative tests of a rotary, air-swept screen have shown that refinements in dust shielding and ventilation of the screen can reduce material emissions from 36.9 pounds per day to less than 0.5 pounds per day; local dust counts were diminished from 12 x 10^6 ppcf to less than 2 x 10^6 ppcf.[4]

Asbestos emissions that accompany the bagging of fibers can be controlled by installing high-volume, low-velocity ventilation hoods (Section 3.3.2) over packing operations. Further, low-volume, high-velocity systems (Section 3.3.2) can, during packaging, collect dust in the immediate vicinity of bag-filling valves and on bag support platforms. Control techniques applicable to the handling of packaged asbestos between the operations of bagging and shipping from the mill are discussed in Section 3.3.2.

As one method of controlling emissions when dry, asbestos-containing mill tailings are placed on a relatively flat disposal pile, a mobile dumper is used at the end of a belt



COLLECTOR	EMISSIONS, lb/hr
1	300
2	100
3	7
4	1
5	6

Figure 3-7. Dust emissions from ore dryers.[4] (Emission based on an assumed rate of 1 lb/hr for bag filters.)

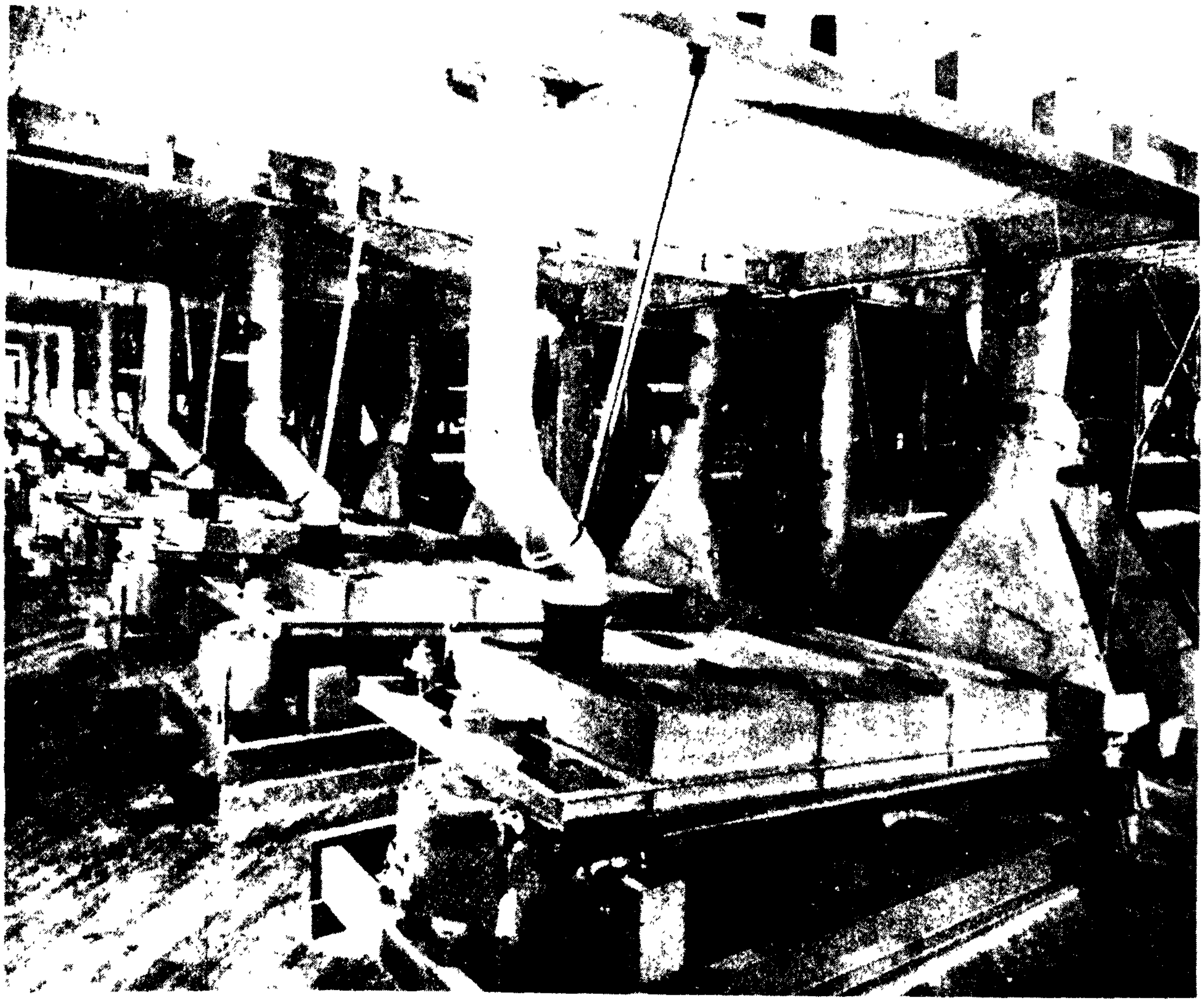


Figure 3-8. Vibrating screens with hooding for dust control.[14]

conveyor that transports the wastes. As disposal proceeds, the location of the dumper is periodically changed in order to maintain the tailings pile as nearly level as possible and thereby minimize emissions caused by shifting the tailings with earth-moving equipment. An inverted funnel mounted to the dumper discharges the wastes in close proximity to the surface of the dump in order to assist in reducing emissions at the point of deposition; however, the elimination of visible emissions at the point of deposition may also require that a water or chemical spray be used. In other milling complexes, mixtures of water and wetting agents have been applied to tailings during their discharge onto waste piles, and this has proved to be moderately successful.[4] Visible emissions generated by the dumping of tailings have been totally eliminated at one domestic asbestos mill by the mixing of tailings with water prior to deposition. This control technique is promising for mills that have access to sufficient water and that can overcome the problem of freezing conditions.

In some cases, asbestos mill tailings form large mounds across which long belt conveyor systems with several transfer points are deployed. The transfer points can be enclosed and ventilated to gas-cleaning devices to provide emission control. Potential emissions from segments of the conveyor system between transfer points can be controlled by enclosing the equipment.

Emissions from the surfaces of tailings dumps can be controlled by providing a protective covering or seal. Because of the large surface areas involved, most of the control methods are expensive. Wherever the eventual surface of the dump is reasonably level, soil can be spread as a sealing medium. The establishment of vegetation on dumps is hindered by the high alkalinity (pH = 9) of the tailings. In preliminary tests, grass has been grown on tailings by first mixing them with the acidic tailings of a copper mine across a soil depth of about 2 inches.[4] Chemical agents that can be sprayed onto waste dumps to form a protective surface crust that is permeable to water are commercially available. The penetration of moisture through the crust controls the potential erosion and disintegration of the cover by heavy rainfall. In some instances, tailings piles from the milling of long-fiber asbestos ores are somewhat self-stabilizing because of the relatively low percentage of very fine dust, the tendency of meteorological conditions to form a layer of larger particles that protect the interior of the pile, and the consolidation of the pile by freezing during long periods of the year.

3.2.3 Control Costs

Standardized conveyor housings that cover the carrying runs of conveyor belts and thereby shield exterior belts and the material being transported from atmospheric precipitation are commercially available. A measure of emission control is also provided by protecting the material from the winds. These housings are typically in the form of curved sections of corrugated sheet metal, one side of which is hinged to the conveyor system. This type of construction permits each section of the belt housing to be lifted so that access is provided to potential blockages of the conveyor system. The additional equipment cost of such housings, above that for completely exposed conveyors, is approximately $10 to $15 per lineal foot of conveyor system, depending upon the width of the conveyor belt.

Complete enclosure of external conveyor systems can furnish more positive control of atmospheric emissions than is possible with conveyor housings. This can be accomplished by providing roof and sidewall coverings for standardized commercial conveyor systems of gallery construction. In this type of system, a truss is employed to support the conveyor system and adjacent maintenance walkways across long spans. The additional equipment cost of an enclosed gallery section is approximately $125 per lineal foot of conveyor in excess of the cost of a corresponding fully exposed system. A standard open belt conveyor, with walkway along one side, is priced at approximately $200 per lineal foot.

Chemical coatings formulated with a non-toxic organic base and commercially available, can be sprayed on exposed material storage or waste piles, such as asbestos mill tailings dumps, to prevent the entrainment of material by ambient winds. Temporary coatings that provide protection for 1 month require from 17 to 170 gallons per acre of surface area at a material cost of $25 to $50 per acre.[16] A typical semipermanent (1 year or longer) coating requires 44[illegible] gallons per acre at a material cost of $480 to [illegible] per acre of area, depending upon the quantity of material needed and the particular coating formulation that is compatible with the material to be encrusted. The cost of application, estimated to be $70 per acre per application, is an important factor to be considered in the determination of which type of coating to apply.

3.3 MANUFACTURE OF PRODUCTS CONTAINING ASBESTOS

3.3.1 Emission Sources in Manufacturing Processes

Many potential asbestos emission sources that are encountered during the manufacture of numerous products have been identified.

Specific examples of such potential sources are:

1. Unloading of asbestos packaged in containers.
2. Warehousing of asbestos packaged in containers.
3. Transporting of asbestos to bag-opening areas.
4. Opening and emptying of containers of asbestos.
5. Unloading and in-plant transporting of asbestos by pneumatic conveyor systems.
6. Willowing (fluffing) of asbestos fibers.
7. Blending and mixing of asbestos fibers.
8. Conveying of dry asbestos-containing materials.
9. Handling of products that bear surface deposits of asbestos dust.
10. Dispersing asbestos dust from workers' clothing.

Packaged asbestos is commonly unloaded from railway boxcars and trucks. Bags, either loosely filled or pressure packed, are attached to pallets by means of tensioned steel bands when large shipments are involved; fork-lift trucks elevate and transport the loaded pallets. In smaller lots, bags are manually handled on an individual basis. When exposed to the atmosphere, fugitive asbestos dust in railway cars and truck bodies and on the exterior of containers can be entrained. The leakage of asbestos-containing material from new or existing punctures in containing bags, in addition to that from bags that are not impervious to asbestos fibers or that are originally sealed in a non-dust-tight manner, can also result in atmospheric entrainment of asbestos. The extent to which the unloading operation is systemized helps determine how often spillage of asbestos fibers occurs.

The storage of containers of asbestos in close proximity to work areas or transportation aisles increases the possibility of packages being ruptured. Even with cautious, systematic procedures, bags of asbestos can be weakened and occasionally broken open during handling. If spilled asbestos is not promptly removed from the floors of storage areas, the fibers can be spread and emitted from the wheels of vehicles and from workers' clothing.

Potential emission sources that accompany the transport of bags of asbestos from storage areas to sites for bag opening are similar to those discussed above for the unloading of packaged asbestos. Emissions to the work space resulting from the accidental puncturing of containers and the airborne entrainment of asbestos dust deposited on packages, pallets, and transporting vehicles can be appreciable.

Asbestos bags are usually opened manually, either with a knife or by impacting them against a stationary blade. Such opening operations and the subsequent dumping of the contents onto a conveyor system or into a loading hopper can emit excessive amounts of asbestos dust if the operator fails to observe appropriate emptying procedures and if the working area is not properly ventilated through a collection hood. The surfaces of emptied containers carry loosely bound asbestos that can become entrained.

Certain short-fiber types of asbestos can be pelletized, transported in bulk quantities, and subsequently unloaded, warehoused, and transferred in-plant at manufacturing facilities by the use of pneumatic conveying systems.[15] Pneumatic railway hopper cars or pneumatic motor vehicle bulk trailers can be loaded at an asbestos mill site and sealed for transport to manufacturing plants that accept this pelletized form of asbestos. For example, railway containers of 60-ton capacity and motor vehicle containers of 20-ton capacity are available. For transfer of the asbestos from a shipping car to a user's intermediate or primary storage bin, a sealed pneumatic conveyor system produces a suction on the loaded car to assist in removing the material.

Gravity hoppers permit unloading to be accomplished without the use of pressure-differential cars or fluidized-hopper cars. The entrained asbestos pellets are subsequently separated from the conveying air stream by a cyclone-type product collector. Unloading rates of up to 10 tons per hour have been demonstrated for a conveyor conduit 4 inches in diameter. From the product collector, the asbestos can be pneumatically conveyed in a compressed air stream to an intermediate or primary storage bin. The use of either a live bottom or a fluidized hopper on the primary storage bin facilitates the eventual continuous, metered transfer of the asbestos to process operations.

The handling of pelletized asbestos results in the freeing of some asbestos fibers and fibrils from the pellets. Consequently, exhausts of conveying air streams from the cyclone product collectors and storage bins cited above are potential sources of atmospheric asbestos emissions. If the air stream exhausted from a product cyclone collector contains an excessive quantity of dust, the protection of the blower that produces suction on the collector requires, independent of air pollution control, that the air be filtered prior to introduction into the blower.

Attempts to reduce emissions from the handling of bags of asbestos have resulted in the increased use of pressure packing. In pressure packing, the asbestos is pressed into a hard, consolidated mass. As a result, the fiber is less likely to leak from the bag, and that which does leak is less likely to become airborne. Several mills pressure pack all fibers except when the order calls for loose-packed fibers.

The longer grades of fully opened asbestos fibers that have been pressure packed are given a willowing or fluffing treatment to reopen the material before further processing is initiated. The severe agitation used to open the fibers produces a strong concentration of dust within the processing equipment; potential emissions are subject to control. Examples of opening machines are willows, vertical openers, carding willows, beating openers, and beating mills.[1] The practice of manually charging and unloading some of this equipment can yield appreciable asbestos emissions to the work space.

Blending and mixing processes that employ dry asbestos involve the mechanical agitation of the fibers in the presence of air. Consequently, these processes are potential sources of asbestos emissions. Specific examples of this type of operation are the blending of synthetic fibers with long asbestos fibers for textile applications, the mixing of silica and asbestos in the manufacture of asbestos-cement pipe, and the mixing of asbestos and bonding resins into formulations for brake and clutch linings. The mixing of the respective ingredients is carried out in a wide variety of equipment, ranging from rotating blending drums to mixing or carding willows.

When materials that contain asbestos in a dry, loosely bound state are transported on open conveyor belts, asbestos fibers can be released into the adjacent work space. The jostling motion induced by the conveyor system and the exposure of a large surface area of material to the surrounding atmosphere are conducive to emissions. Examples of this type of emission source are the transport of asbestos fibers between pairs of textile carding machines and the conveyance of automatically weighed mixtures of synthetic and asbestos textile fibers to a blending machine. More severe mixing occurs at belt conveyor transfer points and can produce appreciable emissions.

If asbestos-containing dust deposits borne on the surfaces of manufactured articles are not promptly removed, emissions during subsequent handling and processing steps can result. Ultimately, these potential asbestos emissions can even carry over to end uses of the products. Dusts formed by the machining of the ends of asbestos-cement pipe to size and by the grinding of asbestos friction products are potential emissions of this type.

Asbestos collected on workers' clothing from exposure to manufacturing processes can be carried outside the plant and emitted into the atmosphere. If emissions from the various processing activities within the manufacturing facility are well controlled, the deposition of asbestos on clothing is minimized.

3.3.2 Control Techniques for Manufacturing Processes

As previously indicated, the handling of uncontained masses of asbestos fiber and the sawing, drilling, cutting, and trimming of materials that contain asbestos can produce significant quantities of airborne asbestos dust. When the general ventilation air of a plant has been contaminated by the emission of asbestos into the work space, potential atmospheric emissions from the discharge of this air to the exterior of the plant can be controlled by maintaining the work space at a slight negative pressure and by treating the exhaust air in a gas-cleaning device. As a preferable alternative to this approach, industry commonly employs an arrest-at-the-source method for collecting this particulate material. An air ventilation system comprised of local dust capture hoods, interconnecting ductwork, fans for air movement (usually on the clean-air side of the collector), and a gas-cleaning device for separating asbestos fibers and dust from the air stream, is used (see Figure 3-9). Some of the benefits of this system are:

1. Reduced atmospheric emissions when a plant at atmospheric pressure is exposed to ambient conditions, as when doors and windows are open.

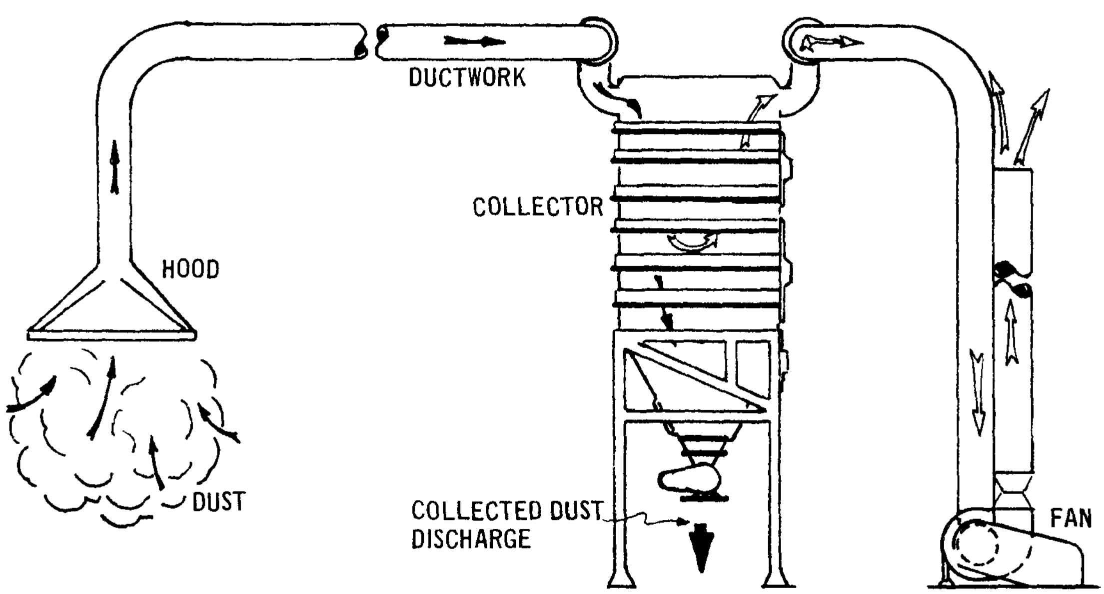


Figure 3-9. Air ventilation system with local dust capture hood.[17]

2. Reduced atmospheric emissions resulting from fibers transported outside of a plant on workers' clothing and on manufactured products.
3. Reduction in amount of plant housekeeping, such as vacuuming of deposited asbestos-laden dust, required for the control of atmospheric emissions.

Two types of ventilation systems are in use, the low-volume, high-velocity design and the high-volume, low-velocity design. In the former case, the velocity of the dust-capturing air stream is relatively large; velocities of 10,000 to 12,000 feet per minute and flow rates of 10 to 250 cubic feet per minute are common.[17] If the hood or nozzle is placed close to the point at which particulate emissions are generated, most of the material is captured, the air flow rate required for a specified degree of capture is reduced, and heavier particles or fibers can be entrained than would otherwise be possible at the same air flow rate. This technique has been successfully applied to the control of emissions from portable power tools and machine tools; Figure 3-10 shows a low-volume, high-velocity system fitted to a radial-arm bench saw. The dust and chips produced during sawing are directed by the saw toward the middle nozzle of the ventilation system; the top nozzle assists in removing material from the blade; and the remaining nozzle removes material from the bench. Figure 3-11 illustrates a second application of the system, a partially enclosed lathe for machining asbestos-cement products. The hood is opened for mounting work in the lathe and closed during the turning operation. A high-velocity air stream captures the products of machining. By contrast, high-volume, low-velocity air ventilation

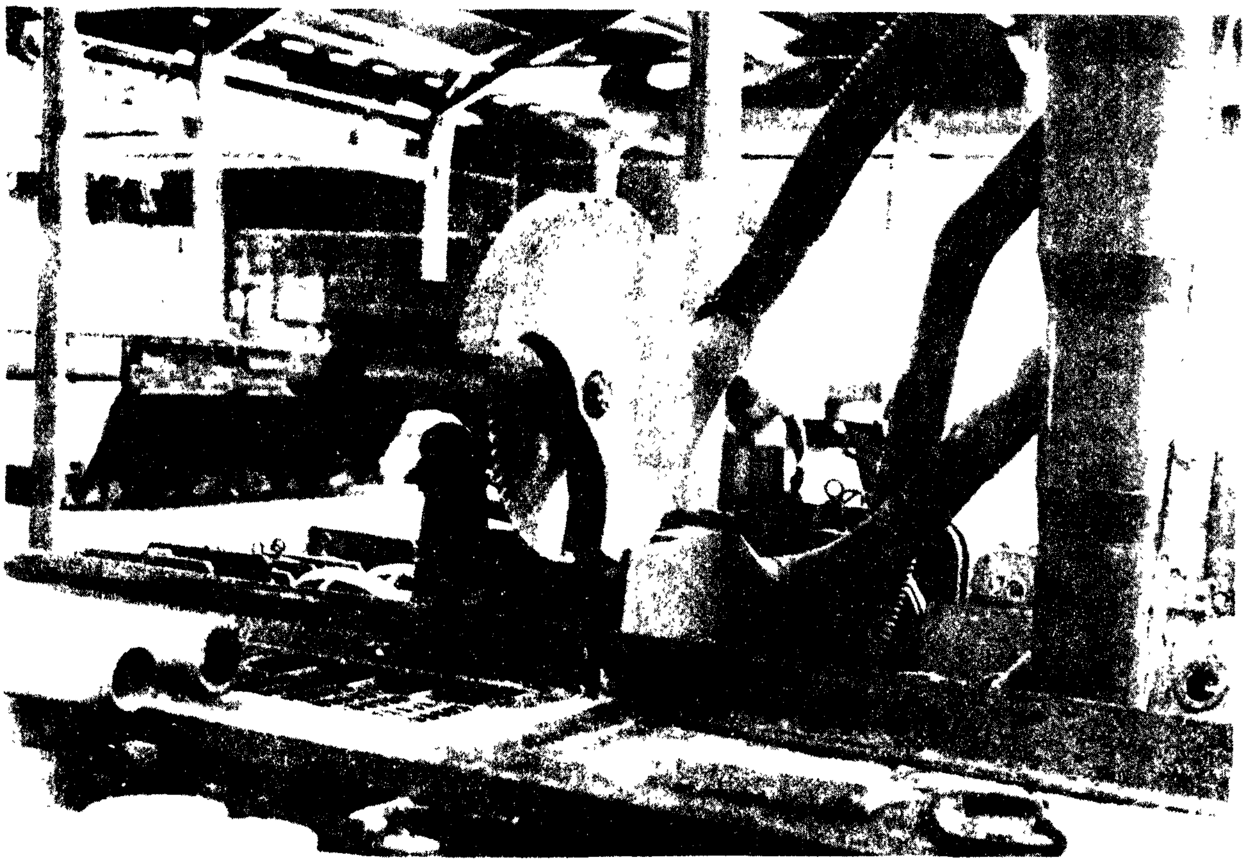


Figure 3-10. Dust capture hoods fitted to radial-arm saw.

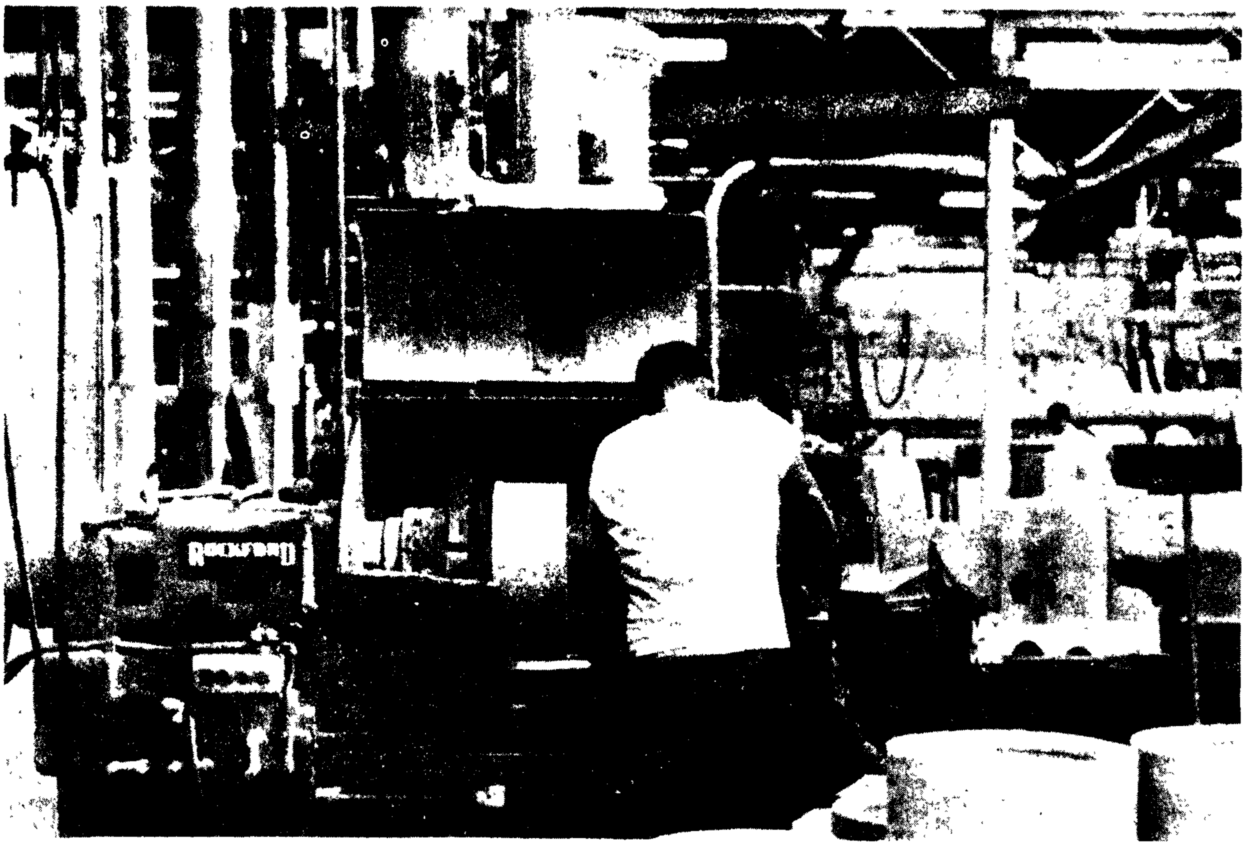


Figure 3-11. Dust capture hood fitted to lathe.

systems are applied to operations in which closely localized capture of particulates containing asbestos is not feasible. These require that an air flow of a velocity of at least 150 feet per minute be induced toward the collection hood.[17] Representative examples include ventilation systems for asbestos bag-opening stations, fiber mixing areas, and asbestos textile cards and looms. Figure 3-12 indicates the configuration of a bag opening and conveying station that is fitted with a dust collecting hood.

A considerable amount of ductwork is required to interconnect the numerous dust capture hoods of a large plant to a central gas-cleaning device such as a baghouse. Circular ducts with a minimum of sharp bends are recommended. To provide for inspection and for the removal of possible accumulated dust from the ducts, access doors should be installed near bends and at appropriate intervals along straight sections of ducting.[17]

The preferred location of the air handling fan for the ventilating system is at the exhaust, rather than at the intake, side of the gas-cleaning device. This places the entire ducting and gas-cleaning system under negative pressure and thereby draws ambient air inward through structural leaks instead of forcing dust-laden air outward.

Methods for controlling dust emissions from belt conveyor systems are illustrated in Figures 3-13 through 3-15.[18] Figure 3-13 shows a hooding arrangement for the transfer of material from a belt conveyor to a hopper. Geometrical configurations and design parameters for the enclosure and ventilation of three types of conveyor transfer points are included in Figure 3-14 and Table 3-2. A method for removing dry dust from the return side of a belt conveyor is shown in Figure 3-15.

Bags for asbestos fiber should be fabricated of dust-tight materials, be sealed

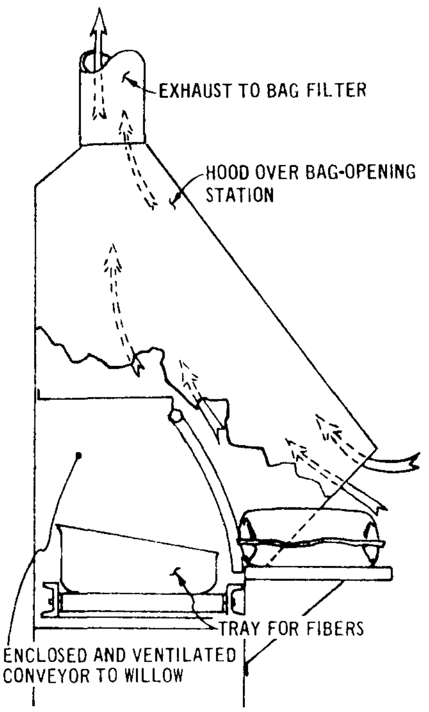


Figure 3-12. Bag opening and conveying station with dust collecting hood.

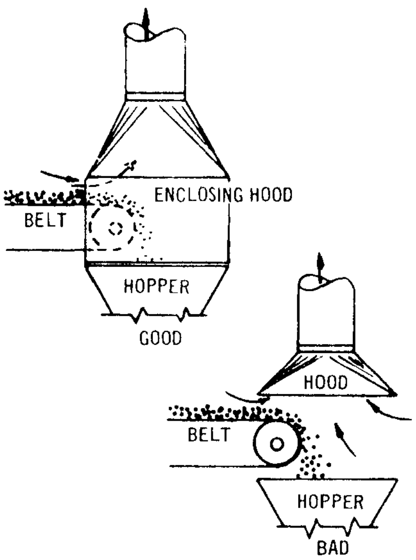


Figure 3-13. Examples of good and bad hood configurations for controlling asbestos-laden dust emissions from receiving hoppers. A completely enclosed source requires less air for control.[18]

dust-tight (e.g., end folded before sewn or stapled), and meet certain strength requirements in order to control emissions. Where possible, bags should be placed on pallets for handling by fork-lift vehicles during shipping and storage operations to minimize the handling of individual bags.

Spilled asbestos fiber that is being handled, stored, or transported in manufacturing plants should be promptly removed by vacuuming or by wet sweeping. Emissions from punctured or ruptured bags can be controlled by repairing bags with masking tape or by placing slipover covers on badly damaged bags. Emissions that result from the manual opening and dumping of bags of asbestos can be collected at the source by a dust capture hood.

The bulk handling of short-fiber asbestos in pellet form is in some instances a means of controlling those emissions that might be generated during the transporting, unloading, warehousing, in-plant transferring, and emptying of asbestos contained in bags. The number of potential emission sources associated with the handling of bags can be reduced; the primary potential source of emissions in bulk handling is the asbestos-containing exhaust streams from pneumatic conveying systems that transport the pelletized asbestos. Pneumatic transporting of pelletized asbestos in bulk quantities is not limited to those processes that can accept pellets directly; where necessary, devices such as impact mills can be incorporated into the handling operation to grind the pellets into an opened configuration prior to introduction into the manufacturing process. Economic and technological considerations, however, limit the use of bulk handling as a control technique to those manufacturing facilities that consume large quantities of asbestos. Pelletizing is presently limited to short-fiber asbestos because of difficulties in briquetting the long-fiber asbestos and in sufficiently opening the long fibers after they are pelletized.

Exhaust streams from pneumatic conveying systems that carry pelletized asbestos can be cleaned by means of conventional fabric filters. Pneumatic conveying systems with integrated fabric air-cleaning devices are commercially available.

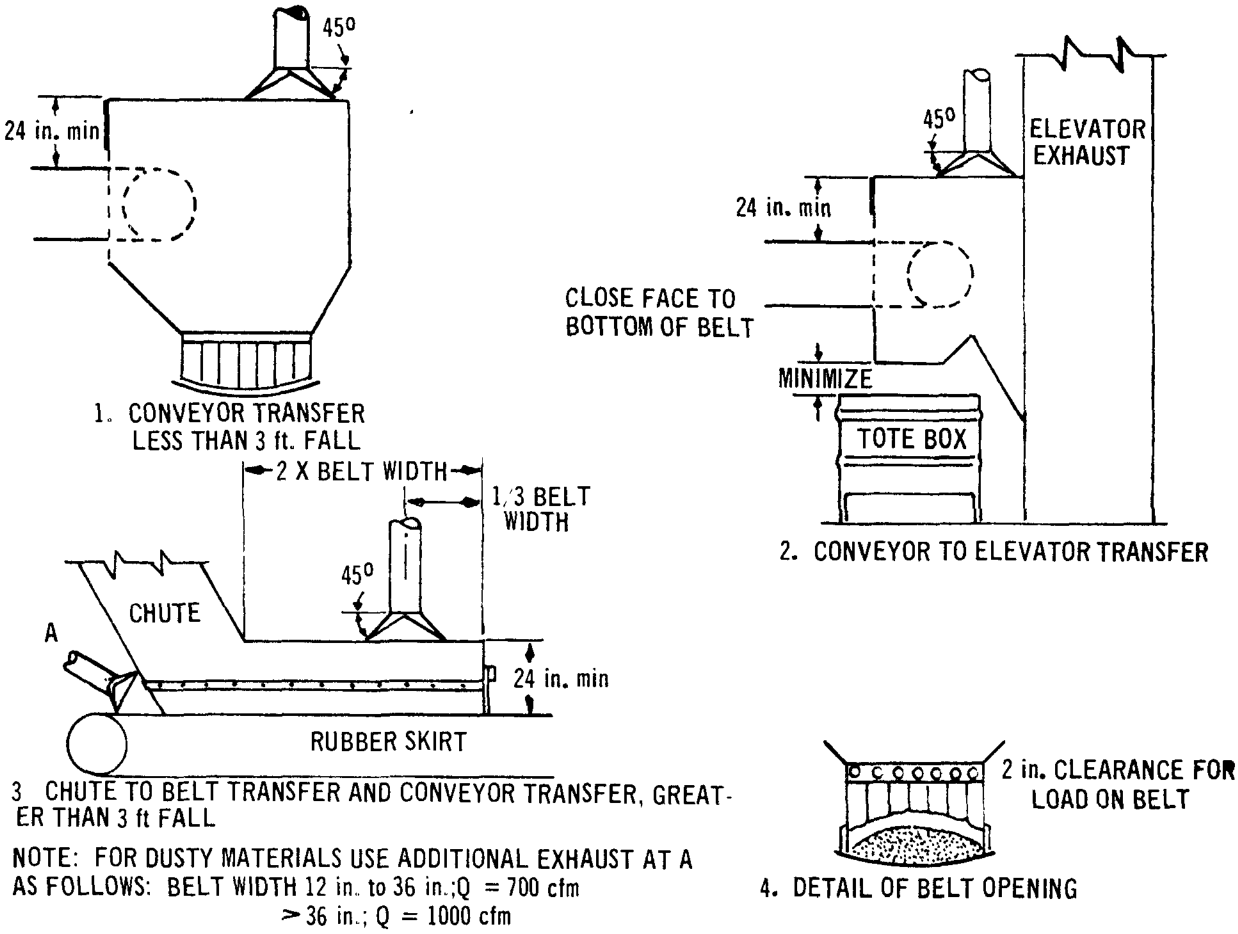


Figure 3-14. System for controlling emissions at conveyor transfer points.[18]

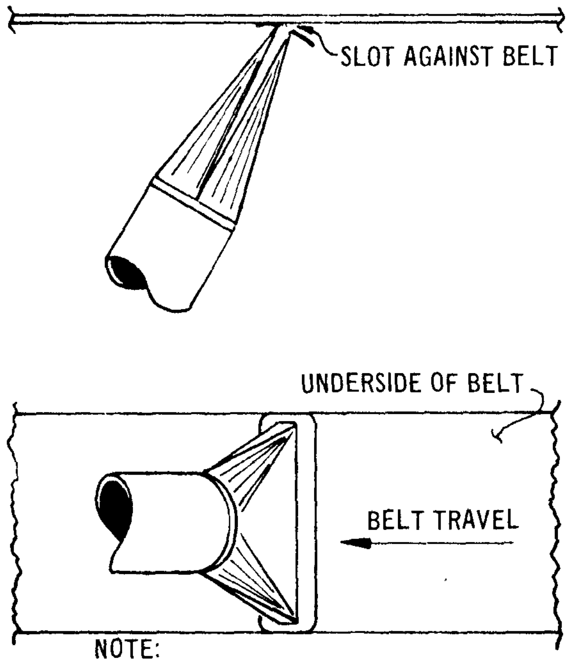
3.3.3 Asbestos-Cement Products

The largest single domestic use of asbestos fibers occurs in the manufacture of asbestos-cement products. These products contain 15 to 30 percent by weight of asbestos, usually of the chrysotile variety. Crocidolite is used to a limited extent, whereas use of amosite is limited because of its low tensile strength. The largest sector of the asbestos-cement industry is that which produces asbestos-cement pipe. Typical applications of the pipe, in sizes ranging from 3 to 48 inches in diameter, involve conveyance of the following materials:

1. Potable, drainage, and irrigation water.
2. Sewage.
3. Industrial products.
4. Air and other gaseous substances for heating, cooling, and gas venting.

Other asbestos-cement products, such as siding shingles and flat or corrugated sheets, are used in a variety of applications.

The interwoven structure formed by the asbestos fibers in asbestos-cement products functions as a reinforcing medium by imparting increased tensile strength to the product. As a result, there is a 70 to 80 percent decrease in the weight of the product required to attain a given structural strength.[19] It is important that the asbestos be embedded in the product in a completely



NOTE:
Q = 200 cfm/ft OF BELT WIDTH
SLOT VELOCITY = 2000 fpm
DUCT VELOCITY = 4000 fpm MINIMUM

Figure 3-15. System for removing dust from return side of dry belt conveyor.[18]

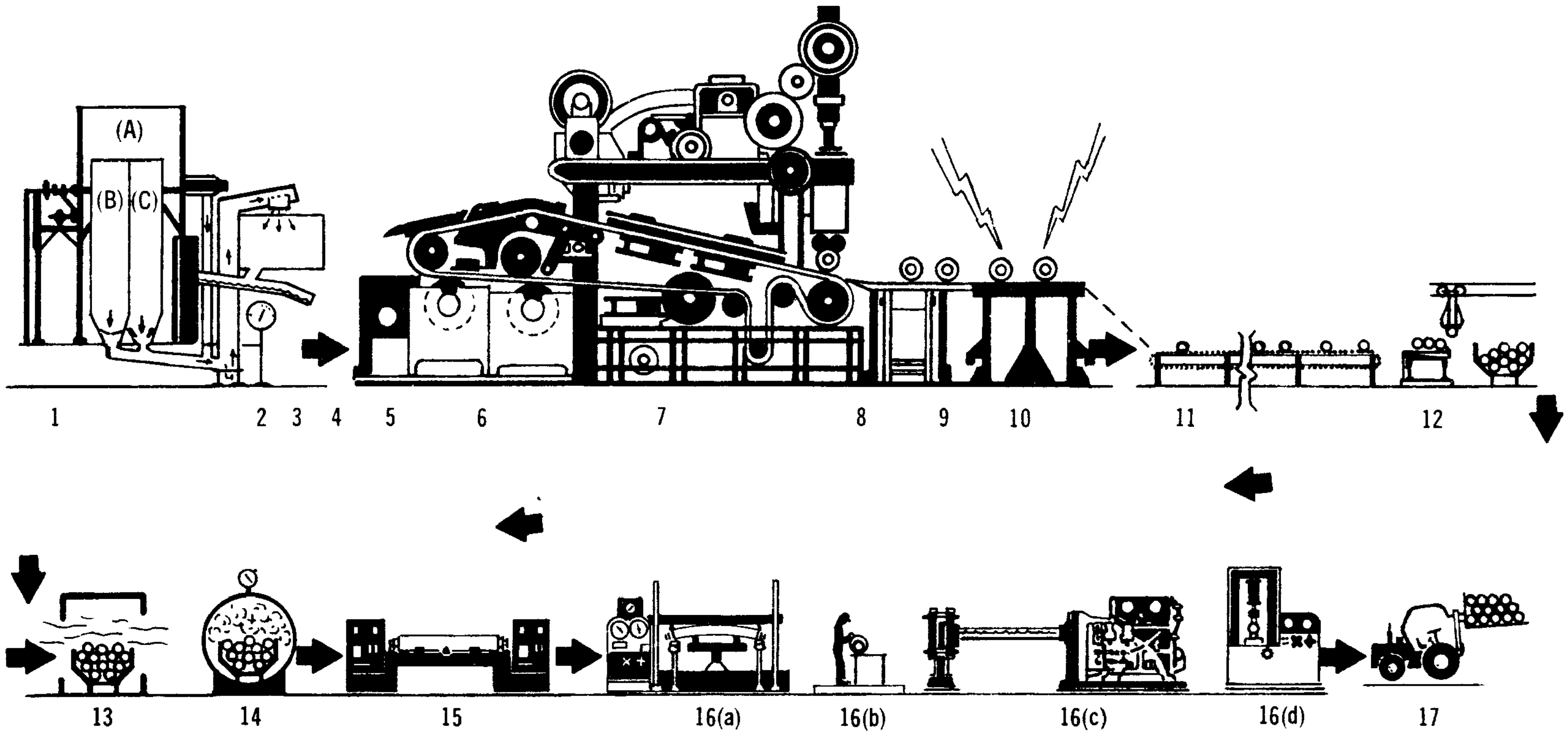
fiberized (willowed) form. The necessary fiber conditioning is frequently executed prior to dry or wet mixing of the fiber with Portland cement and finely ground silica; however, in some cases, this fiber opening is accomplished as the wet mixture is agitated by a pulp beater, or hollander.

Asbestos-cement products are manufactured by the molding process, dry process, wet process, or wet mechanical process; extrusion processes are not widely employed.[19] Articles of irregular shape are formed by the molding process, which accounts for a quite limited production volume. In the dry process, which is not utilized extensively but is suited to the manufacture of siding shingles and other sheet products, a uniform thickness of the mixture of dry materials is distributed onto a conveyor belt, sprayed with water, and then compressed against rolls to the desired thickness and density. Rotary cutters divide the moving sheet into shingles or sheets, which are subsequently removed from the conveyor for curing. The wet process produces dense, flat or corrugated, sheets of asbestos-cement material by introducing a slurry into a mold chamber and then compressing the mixture to force out the excess water. Then, a setting and hardening period of 24 to 48 hours precedes the curing operation. The wet mechanical process, as it is applied to the manufacture of asbestos-cement pipe, is illustrated in Figure 3-16; the equipment is similar in principle to some paper manufacturing machines. In Figure 3-16, the asbestos fiber that has been fluffed and separated by a willow is transferred to a production line bin, weighed and mixed with silica and cement, conveyed by a water stream to a wet mix vat, formed

Table 3-2. CONVEYOR EMISSION CONTROL DESIGN DATA[a,18]

Item	Minimum value
Indraft at all openings	150 to 200 fpm
Air capacity transfer points	
For belt speed less than 200 fpm	350 cfm/ft belt width
For belt speed greater than 200 fpm	500 cfm/ft belt width
For magnetic separators	500 cfm/ft belt width
Belt length between transfer points (30 foot intervals)	350 cfm/ft belt width
Duct velocity	3,500 fpm
Entry loss	0.25 velocity pressure

[a]Good design requires enclosure or covering where practicable.



1. PRODUCTION LINE BINS
   (A) ASBESTOS
   (B) CEMENT
   (C) SILICA
2. ELECTRONIC SCALES
3. DRY MIXER
4. CONVEYING TROUGH
5. WET MIX VAT
6. SCREEN CYLINDER MOLD
7. VACUUM BOX
8. FELT DEPOSITS STOCK ON MANDREL
9. MANDREL (WITH PIPE)
10. ELECTROLYTIC LOOSENER
11. SLOW-DOWN CONVEYOR
12. STENCILLING STATION
13. AIR CURE ROOM
14. AUTOCLAVES
15. LATHES
16. TESTING EQUIPMENT
    (A) FLEXURE TESTING MACHINE
    (B) INSPECTION
    (C) HYDROSTATIC TESTER
    (D) CRUSH TESTER (LABORATORY)
17. MATERIALS HANDLING EQUIPMENT

Figure 3-16. Flow chart for manufacture of asbestos-cement pipe.[20] *(Courtesy of Johns-Manville Co.)*

into a homogeneous slurry, and delivered to cylinder vats for deposition onto one or more horizontal screen cylinder molds. Gravity-dried of excess water through the fine wire mesh screen that forms the circumferential surface of each mold, the asbestos forms a layer of asbestos-cement material, 0.02 to 0.10 inch thick.[19] The layer from each mold is transferred to an endless felt conveyor in order to build up a single sheet for further processing. The sheet is further dried in a vacuum box and transferred to a mandrel, or accumulator roll, which winds the sheet into pipestock of the desired thickness. The pipe section wrapped around the mandrel is removed from the machine and then freed from the mandrel by an electrolytic loosener. Precure time is provided by a slow-down conveyor before the mandrel is removed and the pipe is stenciled for identification. The pipe is transported to a temperature- and humidity-controlled air-cure room before entering the autoclaves where high-pressure steam curing imparts maximum strength and chemical stability. The pipe sections are machined to size on lathes, tested, and transferred to the shipping area.

In the manufacture of products other than asbestos-cement pipe by the wet mechanical process, the layer of asbestos-cement material on the accumulator roll is periodically cut across the roll and peeled away to form a sheet. The sheet is passed through a pair of press rolls to shape the surface and cut the sheet into shingles, is formed into corrugated sheet, or is placed on a flat surface for curing as a flat sheet.

Asbestos-cement products are strengthened by one of three curing procedures: wet curing, atmospheric steam curing, and autoclave curing. The oldest procedure, wet curing, is carried out in a warm, humid atmosphere for 21 to 28 days. Subsequent storage under water for 7 days, frequently performed in the wet curing of asbestos-cement pipe, produces additional strength. Atmospheric steam curing is a form of wet curing in which steam at atmospheric pressure is used to accelerate the wet curing process. In autoclave curing, pressurized steam (100 to 250 pounds per square inch) is used to accelerate the process and initiate the chemical reactions that harden the product.[19]

3.3.3.1 Emissions

Significant amounts of asbestos can be emitted throughout manufacturing processes in which asbestos is not thoroughly wetted to form a slurry. The major sources of potential asbestos emissions during the manufacture of asbestos-cement products by the wet mechanical process are associated with operations that precede the inclusion of asbestos in a wet processing mixture and with those carried out to size the cured products. Wastes dispersed in a wet condition to the vicinity of processing machinery can become secondary emission sources if not removed prior to drying. The possible generation of asbestos-containing emissions when bags of asbestos are opened and when the fiber is dumped into a blender, blended, willowed, transferred to raw material storage bins, and dry mixed is discussed in Section 3.3.1.

Large quantities of dry, asbestos-containing dust are produced when the ends of cured pipe sections are machined to ensure proper mating with connectors. Some characteristics of emissions from finishing operations, as well as from mixing operations, of asbestos-cement pipe manufacture are included in Section 2.4. The manufacture of those asbestos-cement products, such as sheets and siding shingles, that do not require precise sizing by dry machining does not present such severe emission problems.

3.3.3.2 Control Techniques

Potential emissions from those processes beginning with the opening of bags of asbestos and terminating with the inclusion of the fibers in a wet slurry can be controlled by the application of local dust capture hoods as described in Section 3.3.2. The collection of the entrained asbestos-containing dust by a fabric filtering device can control emissions to the atmosphere. Also, asbestos fibers have been conveyed pneumatically from a willow to production line feed bins; this method, in conjunction with a gas-cleaning device for the conveying air stream, can control emissions that would otherwise accompany the transport of dry, loosely bound material on an open conveyor system.[20]

Dust capture hoods, vented to fabric filters, can be used also to control emissions from the machining of pipe ends at the finishing end of the process.

3.3.4 Vinyl-Asbestos Tile

Vinyl-asbestos floor tile, which contains between 18 and 25 percent asbestos by weight, is widely used in residences, schools, public buildings, theaters, and exhibition halls. Attractive features of this product are non-combustibility, resistance to water and dampness, and high strength. Polymers of vinyl compounds are commonly employed as the primary resins.

Various mixers, for example, those of the Banbury type, are employed to knead the plasticized resin binder, asbestos fibers, ground limestone, and pigments into a heated batch of base material. After the base material has been decorated by adding granules of the proper shapes and colors to the material as it passes through a two-roll differential speed mill, the relatively thick sheet is cut and joined to a similar piece that has been previously formed and is in the process of being calendered (smoothed and reduced in thickness between two revolving cylinders). The sheet then traverses a two-roll calender that reduces the sheet to a thickness slightly greater than that of the finished tile; the manufacturing process at this stage is continuous, as opposed to batch. The passage of the tile sheet through a second, and sometimes a third, two-roll calender produces tile of the desired thickness and surface finish. Subsequently, a blanking press die cuts tiles to final size before cooling and hardening of the compound. Waste material is recycled to the mixing operation for immediate reworking.[19]

The flow sheet of a typical vinyl-asbestos floor tile manufacturing operation is illustrated in Figure 3-17.

3.3.4.1 Emissions

Because vinyl-asbestos floor tile is processed as a mass of semisolid material, emissions are limited primarily to those generated by the operations of introducing dry asbestos fibers into the formulation and of mixing the asbestos with other dry granular components of the mix. Semisolid wastes, however, can also generate smaller quantities of emissions if they are not removed from work areas for disposal or recycling. Specific potential emission sources include the handling of packaged asbestos from receiving location to bag-opening site, opening and emptying of bags into raw material bins for the process, dry mixing of the tile compound, and discharge of the dry mixture into a kneading apparatus for the base tile material (see Figure 3-17). Emission sources of this type are discussed in Section 3.3.1. The crushing of waste materials prior to recycling to the process can also generate asbestos emissions.

3.3.4.2 Control Techniques

Dust capture hoods of the high-volume, low-velocity type discussed in Section 3.3.2 can be employed to ventilate bag opening and dumping areas, dry mixers, and equipment for crushing scrap material in the manufacture of vinyl-asbestos tile. The gas streams can be subsequently cleaned by passing them through fabric filtering devices before exhausting the dust control air streams to the atmosphere.

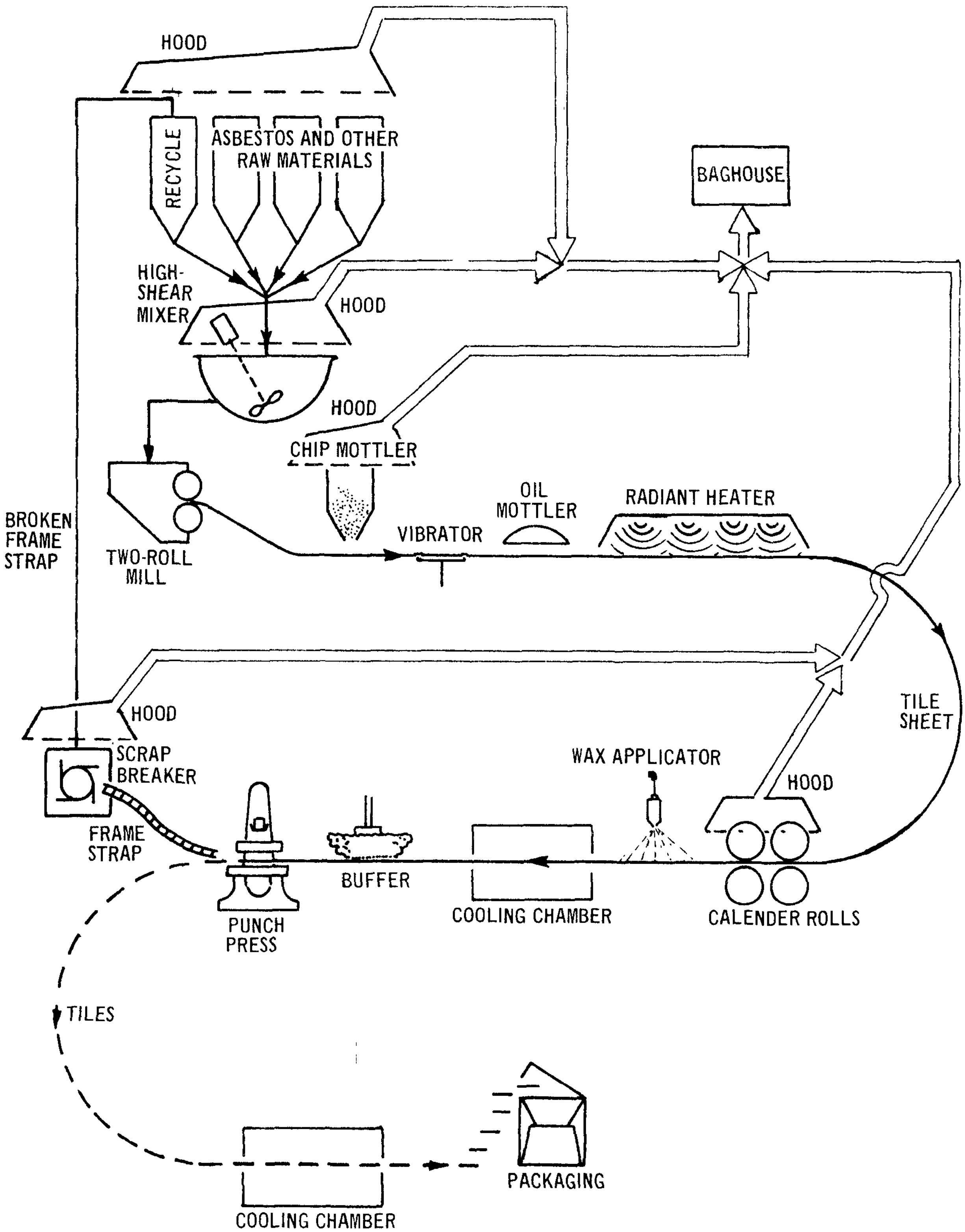


Figure 3-17. Flow chart for the manufacture of vinyl-asbestos floor tile.

3.3.5 Asbestos Paper

Asbestos paper, containing chrysotile as the principal type of asbestos, has a wide variety of uses; Table 3-3 indicates the extent of these applications.[21] Frequently, product requirements dictate that other materials be combined with the asbestos paper. For example, asbestos paper is impregnated with asphalt to form asbestos felt roofing and pipe wrapping; in addition, the paper is sometimes laminated into plastic molded articles to provide reinforcement and thermal stability. A primary user of asbestos paper is the electrical equipment industry in which the paper serves as a low-cost, thin spacing material that possesses desirable electrical insulating and heat resisting properties. This industry requires paper produced from specially processed asbestos fibers from which the iron oxides have been removed.

Asbestos paper is manufactured on machines of the Fourdrinier and cylinder types that are similar to those that produce cellulose paper. The cylinder machine is much more widely employed.

The operation of a Fourdrinier paper machine is shown in Figure 3-18.[19] The mixing operation combines short-fiber asbestos with binders selected for the desired properties and application of the paper. Typical binders are starch, glue, water glass,

Table 3-3. USES OF ASBESTOS PAPER

Air cell and other pipe coverings
Boiler jackets
Asbestos roofing felt
Asbestos-protected metal roofing
Gaskets (plain and metal reinforced)
Wicks in oil burning apparatus
Tubes for electrical insulation
Electrical insulation of wire and cable
Insulation for hot air pipes
Linings for stoves and heaters
Linings for filing cabinets, cartridges, carpets, auto mufflers, drum controllers, cookers, electrical appliances, armored car roofs, motors, etc.
Drip catchers in enameling ovens
Insulation for ovens and dry kilns
Table pads and mats
Insulation in heat- and chemical-resistant reinforced plastic pipe and other laminated products
Diaphragms in electrolytic cells
Tank covers
Filters
Protection from heat in welding and other processes
Crumbled paper in annealing
Insulation in chemical and physics laboratories
Insulation for automobile exhausts
Clutch facings in automatic transmissions
Baking sheets
Hot-air ducts or linings of paper ducts for hot-air service
Base for floor covering
Saturated paper for cooling tower fills

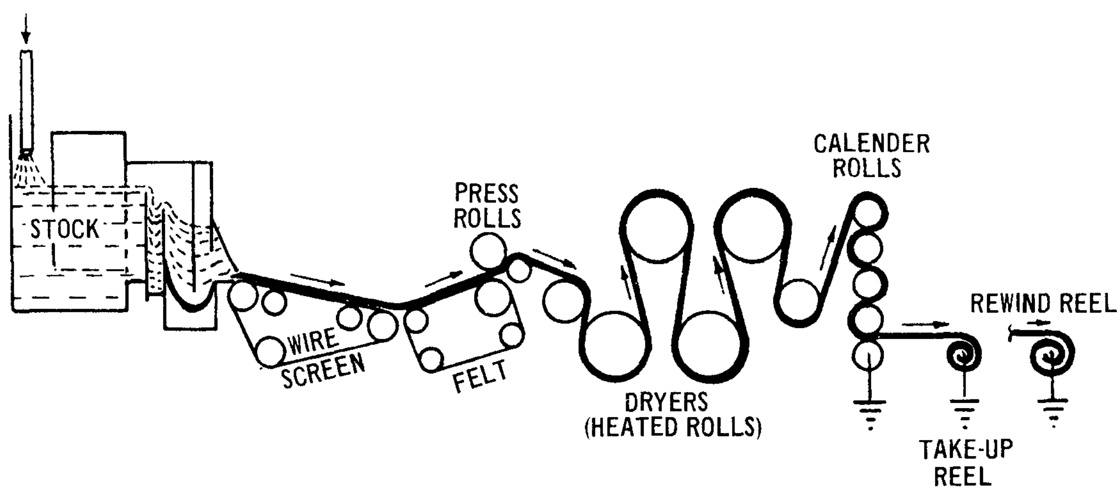


Figure 3-18. Fourdrinier paper machine.[19]

resins, latex, cement, and gypsum.[1] A pulp beater, or hollander, mixes the asbestos, binder, and water into a stock that typically contains between 6 and 12 percent fiber. After it exits from the stock chest, the stock is diluted to as little as 1.5 percent fiber in the discharge chest. From the discharge chest, a thin, uniform layer of the stock is deposited by gravity onto an endless, moving wire screen through which a major portion of the water is removed by suction boxes or rolls adjacent to the sheet of paper. The sheet is then transferred onto an endless, moving felt and pressed between pairs of rolls to bring the paper to approximately 60 percent dryness.[19] Subsequently, the continuous sheet of paper passes over heated rolls, while supported on a second felt, to effect further drying. This is followed by calendering of the paper to produce a smooth surface and cutting the paper to size as it is wound onto a spindle.

The operation of a cylinder paper machine includes a mixing operation for stock, as indicated for the Fourdrinier paper machine. The stock is then delivered, however, to a cylinder vat for deposition onto a horizontal screen cylinder mold. The fine wire screen that forms the circumferential surface of each mold permits water to be removed from the underside as a layer of slurry is picked up by the mold. As the layer of paper is transferred to an endless belt conveyor, the paper is sandwiched between two layers of felt and is then passed over vacuum boxes in order to remove some of the water. The subsequent press rolls, drying rolls, and calender rolls are similar to those described for the Fourdrinier machine.

Both types of paper manufacturing incorporate the recycling of the asbestos-containing water, or "white water," which is removed from the stock prior to passage across the heated drying rolls. Little asbestos is lost to waste.[19]

3.3.5.1 Emissions

In addition to the emissions that occur during handling operations as asbestos is brought to the preparation end of a paper machine, there are potential emissions from the mixing of ingredients in a pulping mill. Since this mixture is next converted into a thin slurry for further processing, the potential for the subsequent emission of asbestos into the work space is diminished until the paper has been dried. Wet wastes can, however, eventually generate emissions if not removed for disposal. The slitting of finished stock, 3 to 12 feet wide, by knives while it is winding onto spindles can produce asbestos dust.

3.3.5.2 Control Techniques

The control of asbestos emissions from dumping of bags and from dry mixing is accomplished by the use of high-volume, low-velocity dust-capture hoods as described in Section 3.3.2; passage to a fabric filtering device provides control of potential atmospheric emissions. Additional control can be provided by the use of pulpable bags that can be added to the mix (which obviates the need to open the bags). Emissions from the slitting process are subject to control at the source by low-volume, high-velocity dust-capturing devices as discussed in Section 3.3.2.

3.3.6 Friction Materials Containing Asbestos

Asbestos-containing friction materials are used extensively in the fields of transportation, mining, and heavy construction. Specific applications are of drum, disk, outer jaw, and band brakes and in dry and oil-immersed clutches.

The various types of friction materials can be classified according to structure and method of fabrication. Molded brake linings or clutch facings encompass all products that are preformed under pressure in molds or between rolls; materials included are friction compounds, asbestos fibers, sulfur, zinc oxide, litharge, rubber, and resins. Paper and millboard friction materials include plied asbestos papers that are impregnated prior to or subsequent to plying and asbestos papers that are formed from pulp to which friction compounds have been added.[19] Woven linings are constructed of resin-impregnated woven asbestos fabrics that are hot pressed or calendered and baked to form linings.[19] The classes of bonding materials are drying oils, plastics, bitumens, and natural and synthetic rubbers;[1] they are used either separately or in combination and either in the presence or in the absence of solvents. Rubberized linings are widely used except when high temperatures are involved.[19] The variety of asbestos predominantly used in the applications mentioned is chrysotile.[19]

Desirable characteristics of friction materials are (1) the maintenance of a constant coefficient of friction under varying contact stress, moisture, and temperature in combination with (2) minimum wear of the friction material and corresponding bearing surface. Although all common friction materials become inoperative when immersed in water, the materials are designed to shed the water quickly and recover fully. Quality control must be sufficient to ensure the attainment of uniform properties so that hazardous, unbalanced braking will not occur. In addition, the structural integrity of the friction material must be maintained at the high temperatures inherent in braking and transmitting energy.

In the manufacture of friction products, many materials are used in varying proportions in order to design the product for a particular application. Since the exact roles of many of these constituents are not known, the products are designed on the basis of results of operational tests. For example, the addition of 1 percent of 600-mesh aluminum oxide increases the frictional resistance by approximately 15 percent.[22] Most brake linings are self-scavenging (i.e., self-cleaning of congealed binder), but some require a scavenger, such as 40-mesh brass chips.[22]

Ribbon blenders are frequently utilized to mix the bonding agents, metallic constituents, and asbestos fibers in the production of molded linings by dry processes. The major binder for dry processes is a "b" stage resin that is thermoset when fully cured, but is also intermediately set in the partially cured condition.[22] A uniform layer of the material is heated sufficiently, under pressure, to cause the resin to flow and set but not be fully cured. The resulting flat sheet is removed, cut into product-sized segments, reheated to soften the resin, and formed to the proper arc by cold molding, which resets the resin. A final baking of the segments in compression molds at 1000 to 4000 pounds per square inch to retain the shape converts the resin to a thermoset or permanent condition.[19] Figure 3-19 illustrates the manufacture of brake linings by a dry-mixed molding process in which curing is performed in multiple stages.

Wet-mixed molding materials are commonly combined in a sigma blade blender for incorporation into a wide variety of manufacturing processes. In the wet board process, the mixture is fed to a paper machine where the material is placed in a preform, which carries a perforated metal screen on one side; when suction is applied to the outside of the screen, solvent is removed and a deposit of the molding mixture remains on the screen.[22] The deposit is transferred to a revolving cylinder, where it builds up to the product thickness. The deposit is removed from the cylinder, dried, cut into product-sized segments, saturated in a liquid binder, and either air-dried or oven-dried to remove the solvents. The binder at this stage is still sufficiently flexible to allow forming in a curved mold for final curing. In an alternate process (see Figure 3-20) for less dilute mixtures, a free-flowing but slightly tacky mixture is forced from a hopper into the nip of two form rollers which compress the mixture into a continuous strip of friction material.[22] Sometimes the mixture consists of damp aggregates, which must be ground in

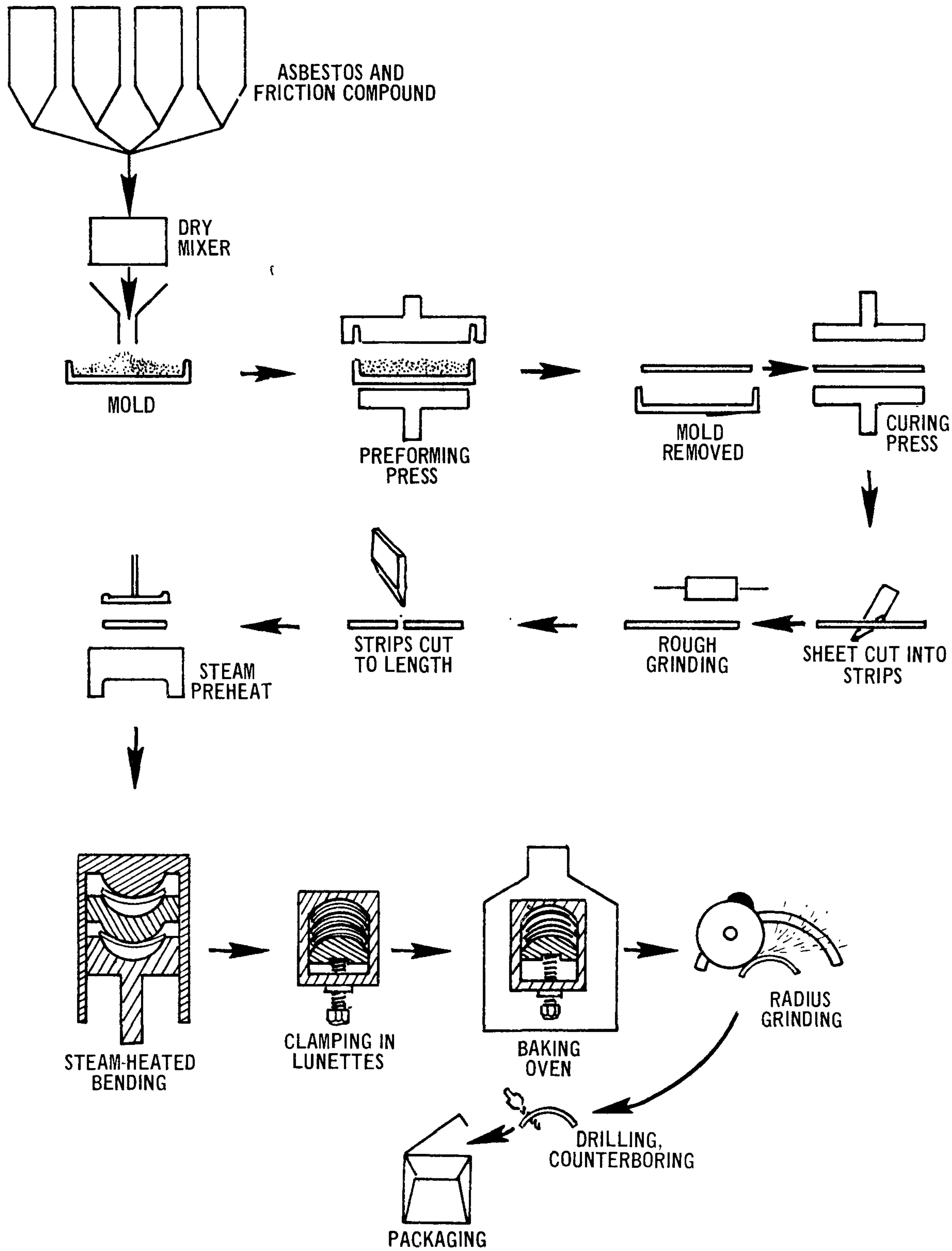


Figure 3-19. Manufacture of dry-mixed molded brake linings.

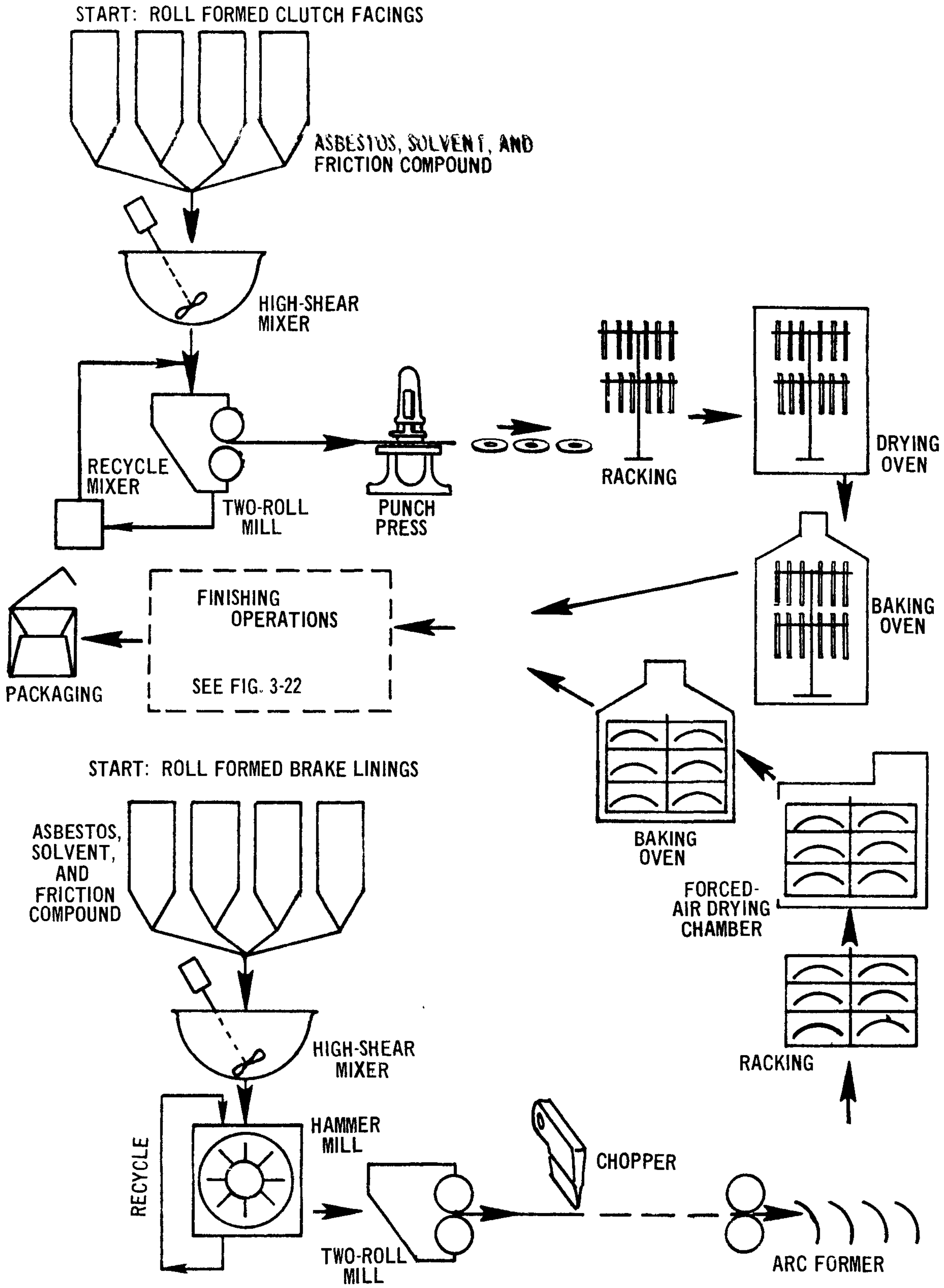


Figure 3-20. Two-roll forming of brake linings and clutch facings.

order to ensure homogeneity. The continuous strip is either cut to length to form brake linings or punch pressed to produce clutch facings prior to curing in pressure-clamped forms. A variation of the process is the introduction of a thin wire mesh on the bottom to form a product with improved heat conduction properties.[22] In a manner similar to the roll extrusion (two-roll forming) of a damp mixture, the sheeter process feeds a mixture of solvated rubber and asbestos fiber into the nip of a large, heated roll and a small, cold roll, which rotates in the opposite direction.[22] As the plastic mixture builds up slowly on the heated roll, the gap between the rolls is automatically enlarged. The sheet is slit from the roll in product-sized widths and formed and cured in the same manner as those in other wet processes. Standard plastics extrusion machines with orifices of appropriate profile are also employed to shape wet-mixed molding materials into a continuous tape.[19] After extrusion, the tape is dried in rolls, cut to size, and finish-cured to shape in compression molds.

Woven brake linings and clutch faces frequently are manufactured of high-strength asbestos fabric reinforced with wire; brass wires of 5-mil diameter or larger are commonly used. The fabric is predried in a batch oven, continuous process oven, or autoclave. The fabric is impregnated with resin by several techniques: (1) immersion, (2) introducing the binder into an autoclave under pressure, (3) introducing dry impregnating material into carded fiber prior to the production of yarn, or (4) forcing the binder into the fabric from the surface of a roll. After the solvents have dried from the binders, the fabric is densified by calendering or hot pressing, cut to length, cured, and machined to produce brake linings (see Figure 3-21). Endless woven clutch facings are produced by a similar process in which the facings are blank-pressed from saturated cloth. Figure 3-22 illustrates the manufacture of endless wound clutch facings by the process of slitting impregnated cloth into narrow (less than 1/2 inch) strips or using impregnated yarn, spiral winding the strips around a mandrel, densifying and curing the preform, and machining to finished specifications. Ranges of compositions for these products are 40 to 60 percent asbestos, 10 to 20 percent cotton, 20 to 40 percent wire, and 5 to 20 percent binder.[19]

Friction materials are either riveted or cemented to the carrier structure. Thin (1/32 inch) friction materials, such as are used in automatic transmission plates, can not be riveted practically. Bonding by the use of heat-setting cements, such as phenol formaldehyde, allows longer wear since the lining can be worn more closely to the carrier member.[22] For large bonding production, the cement is applied in a solvent by spraying or roll-coating one of the two members being bonded. The coated member is passed through a low-temperature oven to drive off the solvent, and then the friction material and carriers are assembled in fixtures and baked by passing the clamped assembly through a conveyor oven or high-frequency unit to flow and set the cement.[22]

In order to supply brakes for an annual brake lining replacement market in excess of 25 million vehicles, more than 500 brake relining companies debond worn, cemented, brake linings in order to reuse the metal brake shoes.[23] Debonders vary from small-scale, batch process companies that debond and reline less than 50,000 shoes per year to brake lining manufacturers that utilize mechanized, continuous process equipment for debonding and relining. The debonding relies upon the incineration of the adhesive portion of the lining at temperatures that will not warp the shoes. A typical small-scale debonder (see Figure 3-23) utilizes a 55-gallon drum as the primary combustion chamber for a batch charge of 200 brake shoes. The primary gas burners are designed to heat the charge to 850°F to initiate combustion of the adhesive. After ignition of the adhesive, the gas flow to

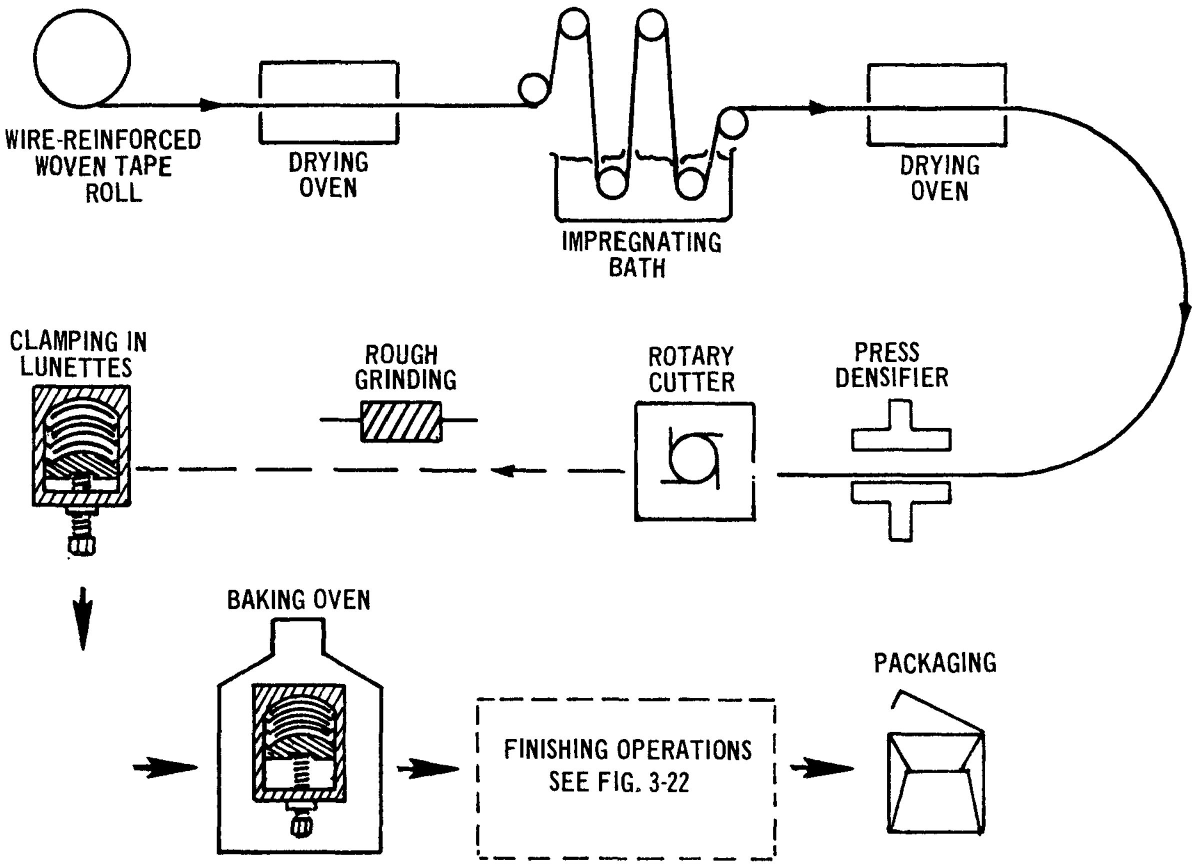


Figure 3-21. Manufacture of woven brake linings.

the primary burners is stopped and combustion is maintained below 1000° F until all the organic constituents are consumed. As the adhesive chars, the linings usually fall off the shoes; however, occasionally the shoes must be tapped lightly to accomplish separation. After cooling, the metal shoes are blast-cleaned, soaked in solvents and surface preparations, pressure-assembled with new linings, and heated to 650° F to thermoset the bond. Following a grinding operation to ensure a true braking surface, the assemblies are packaged for sale as sets of four shoes for two wheels.

3.3.6.1 Emissions

Aside from emissions related to the handling of asbestos in bags, operations that involve asbestos in certain dry-mixed molding compounds (such as weighing of raw materials, charging of mixers, blending of component ingredients, and discharging of mixers) are major potential emission sources in the production of friction products. Finishing operations, however, can generate much greater quantities of asbestos-containing dust from the use of band saws, abrasive wheels, drills, cylindrical grinders, disk grinders, and circular saws. For example, the drilling and grinding of brake linings during manufacture release as much as 30 percent of the lining material as waste.[23] Brake debonders are not considered to be major sources of asbestos emissions since the adhesives are burned without any physical disruption of the surface integrity of the brake linings. Data that quantify the percentage of asbestos in the particulate matter and the extent of thermal degradation of the asbestos are not currently available.

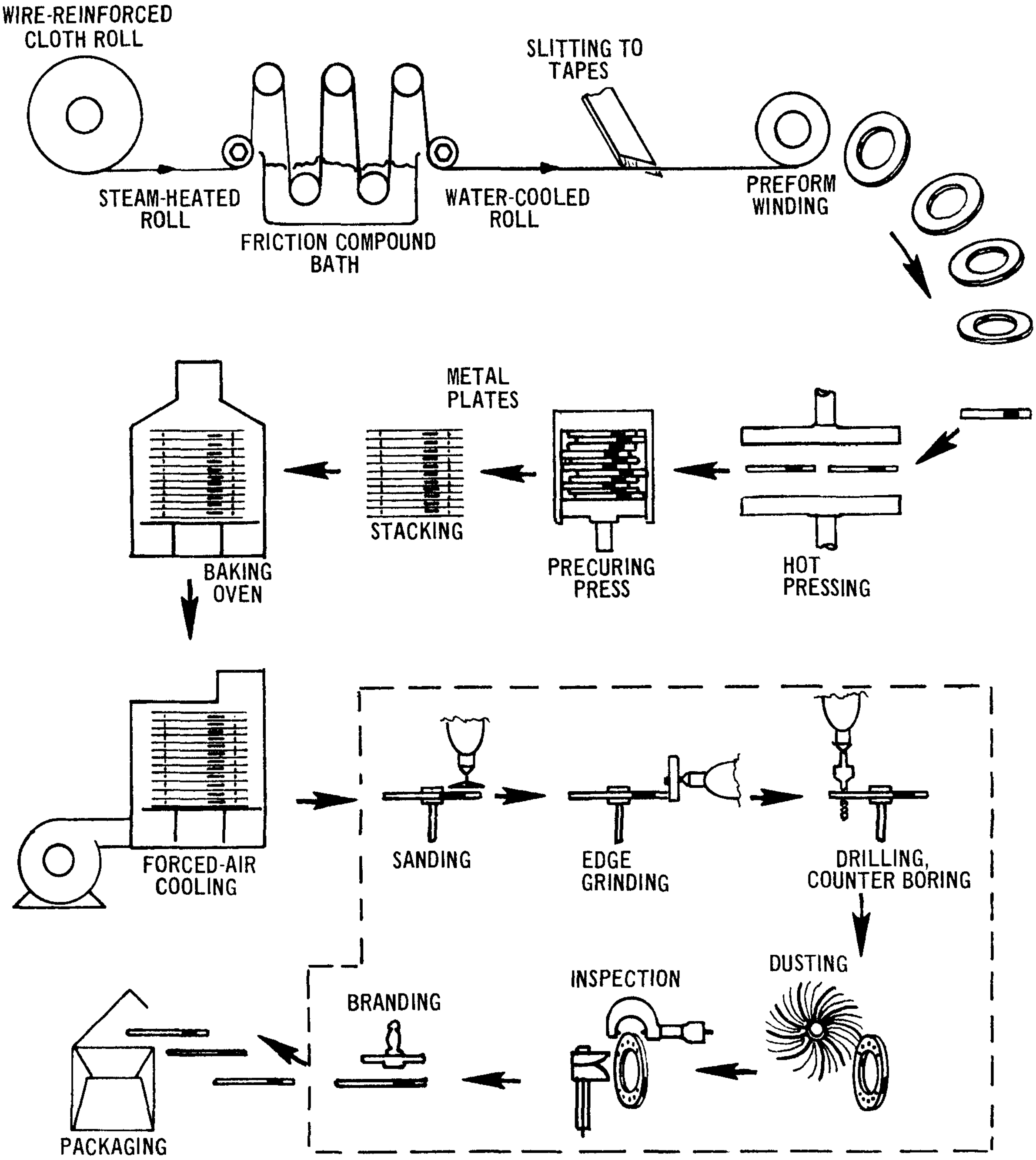


Figure 3-22. Manufacture of endless wound clutch facings.

3.3.6.2 Control Techniques

As in the manufacture of numerous other asbestos-containing products, emissions from the production of asbestos friction products are controlled by applying dust capture hoods. Hoods of both the low-volume, high-velocity and high-volume, low-velocity types described in Section 3.3.2 are applicable. Dust entrained in the air streams is frequently cleaned with fabric filtering devices. In order to avoid fire hazards inherent in the dry collection of some solvent fumes, high-energy wet collectors have been utilized. Almost all brake debonders employ gas afterburners capable of raising the temperature of the

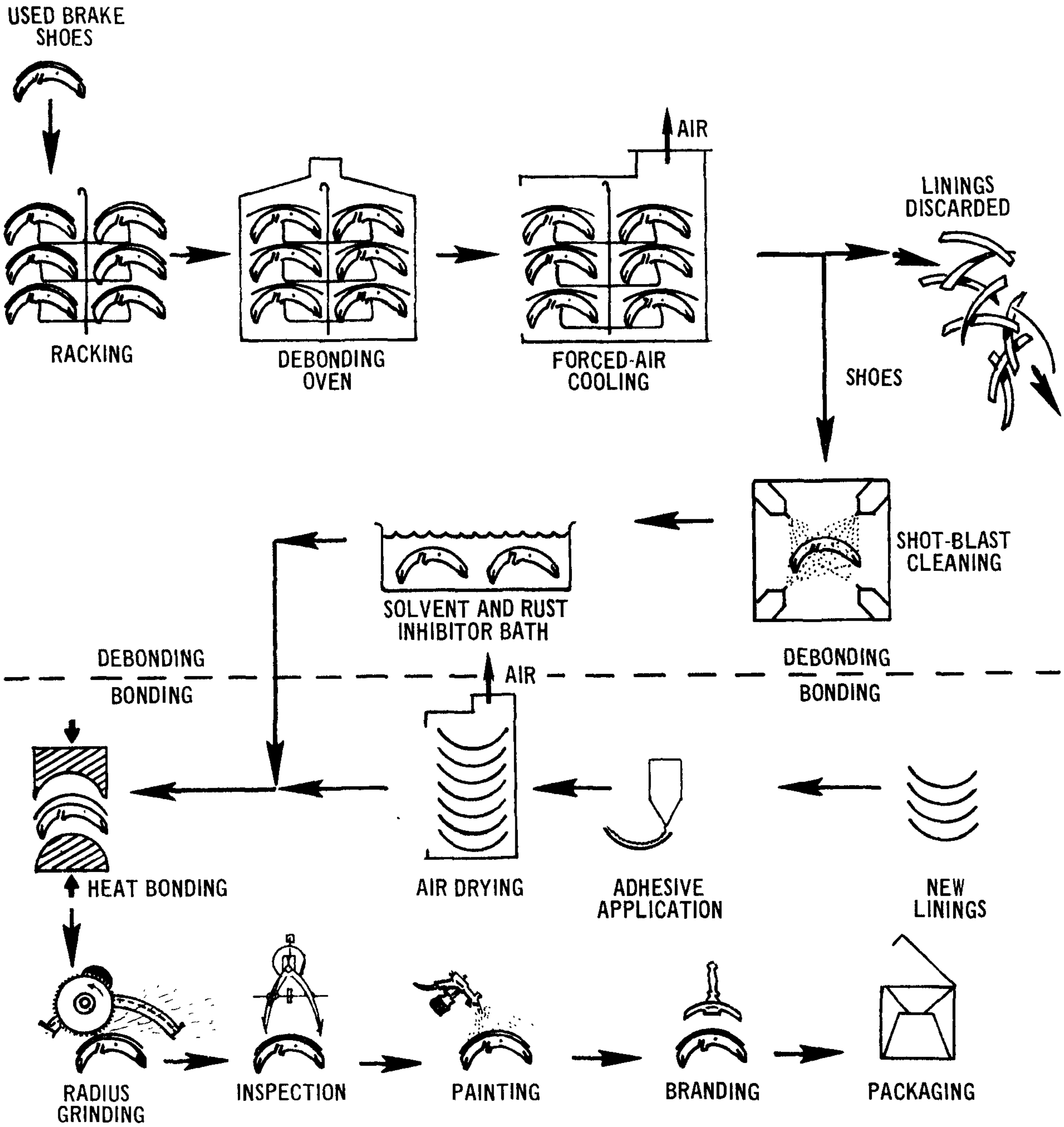


Figure 3-23. Process of debonding and bonding brake shoes.

effluent to between 1400° and 1800°F. Proper operation of such an afterburner can eliminate visible emissions and reduce particulate emissions to below 0.05 grain per standard cubic foot at 12 percent CO_2.[24] Conclusive data on the thermal degradation of asbestos is not available; the asbestos content of the effluent is considered to be unchanged by the afterburner.

3.3.7 Asbestos Textile Products

Of prime importance relative to the inclusion of asbestos in textile products are the properties of exceptionally strong resistance to the action of heat, fire, acids, and mechanical abrasion. The textile grades of asbestos require fibers that are preferably long, fine, and flexible, and possess superior tensile strength. Of the five varieties of asbestos utilized industrially, only chrysotile, crocidolite, and amosite have these properties to a degree that justifies their use in textiles; chrysotile is the dominant variety. Textile goods of interest include roving, carded lap, yarn, cord, rope, square-plaited goods, braided tubing, tape, webbing, and cloth. Figure 3-24 illustrates the operations required for the production of various asbestos textile products.

The majority of the fibers received by the textile plant are of the milled variety. Crude or unmilled fibers in the form of small unopened fiber bundles are sometimes used, however, and must be processed through an edge mill or other milling device to effect preliminary opening and removal of waste products. The output from the milling operation is delivered to vibrating screens, where the fibers are removed by an air aspiration system and graded. Pre-milled (opened) fibers have frequently been compressed during packaging for shipment and must be separated and loosened again. This action is accomplished by passing the fiber through a fluffer.

Either in a preliminary mixing process or during carding, the separated asbestos fibers are blended with small amounts of organic fibers, such as cotton or rayon, which function as carriers and supporting agents for the shorter asbestos fibers, thereby improving the spinning characteristics of the asbestos. The usual organic fiber content is between 20 and 25 percent. The blended fibers undergo a final opening and cleaning process by the carding machine, which combs the fibers into a parallel arrangement to form a coherent mat of material. Next, strips, or slivers, are separated from the mat and mechanically compressed between oscillating surfaces into untwisted strands. These strands are wound onto spindles to form the roving, from which asbestos textile yarn is produced.

By the twisting and pulling operations performed by a spinning machine, the relatively weak roving is converted into a stronger structure, yarn. Spinning machines used are the single-wire or double-wire machines of the fly-frame type and the ring type, which are similar to those that work cotton and worsted yarns.[1] In comparison with normal organic yarns, asbestos-containing yarns can be drawn only slightly, however.

Asbestos twine or cord is produced from yarn by twisting together two or more yarns on a fly- or ring-type spinning frame in a manner similar to that used in the production of cotton cord. Braided asbestos textile products are manufactured on various types of packing braid machines. More than one type of machine is needed because of the desire to impart various shapes to the products by the plaiting operation rather than by mechanical deformation. Asbestos yarns are woven into fabric on looms that operate similarly to those that produce conventional cloth goods.

3.3.7.1 Emissions

In the manufacture of asbestos textile products, emissions can result from unloading, warehousing, transporting to bag opening areas, bag opening, and dumping of asbestos, as discussed in Section 3.3.1. The fluffing operation, which is also noted in that section, and the grading operation involve beating and combing processes that generate heavy dust concentrations. These concentrations can escape to the surrounding environment if equipment enclosures do not have suitable local exhaust ventilation and fabric filters. A considerably larger amount of dust results from fly willowing to recover fibers from wastes collected by cyclones.[25] Both the blending of various grades of asbestos fibers and the blending of asbestos with non-mineral fibers involve dumping of dry materials into hoppers and, frequently, automatic weighing of them prior to depositing onto conveyor belts, which discharge into a blending machine. Potential emissions associated with blending or mixing operations are identified in Section 3.1.1.

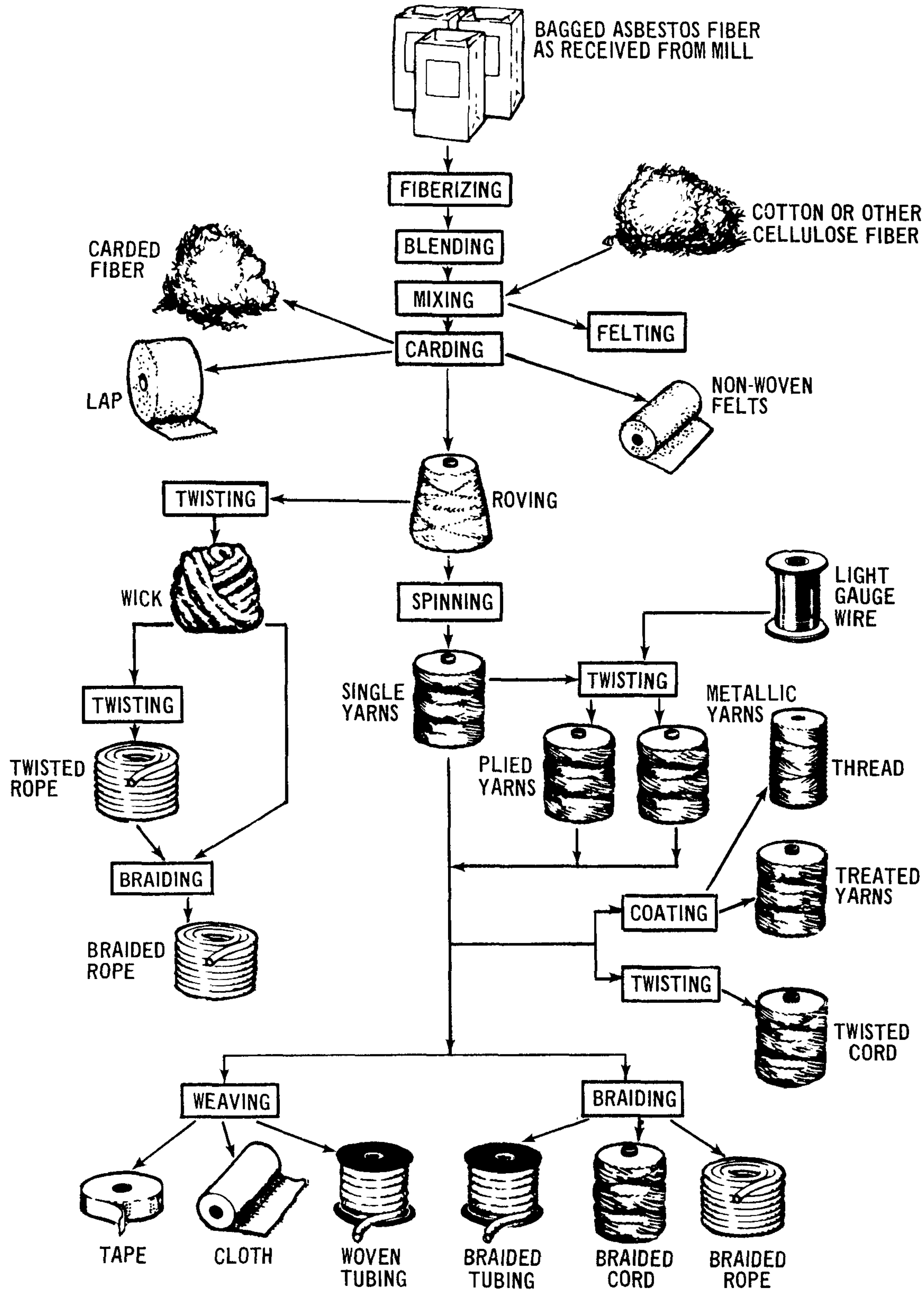


Figure 3-24. Manufacture of asbestos textile products.[14]

Fiber blends are often loaded by hand into mobile hoppers, transported in these open bins to carding machines, and then manually loaded into the cards. These operations result in significant emissions of asbestos to the surrounding work space. Asbestos-containing dust is generated from the swift roller of carding machines as the worker and stripper rollers assist in converting the masses of blended fibers into coherent blankets of material. The periodic cleaning of cards, perhaps on an interval of 7 to 10 days, can release large amounts of dust and fleece to the surroundings.[26]

The major source of asbestos emissions from twisting machines is the release of material from the yarn undergoing twisting as it is rapidly whipped through the air.[25] An end of roving is supplied from a jack spool, passed over rollers and guides, and then rapidly wound onto a spindle as twisted yarn. Emissions also result from the breakage of yarn and the subsequent rotation of the loose end by the spindle.

Weaving potentially generates more dust than any other textile operation; however, present control technology can reduce emissions to the extent that this process can be one of the cleanest of all textile operations.[26] It has been suggested that the principal emission source is the abrasion of yarn against eyelets of heddle frames as the frames move upward and downward in the weaving process.[25] Emissions also accompany the rapid traversing of the shuttle and fill yarn across the width of the fabric.

3.3.7.2 Control Techniques

Direct emissions from asbestos textile plants to the atmosphere are frequently controlled by the use of fabric filtering devices. In some cases in the United States, it has proved to be economical to control the temperature and humidity of ventilating air of large work spaces such as carding, twisting, and weaving rooms. Flow capacities capable of changing the entire volume of air in these work spaces as frequently as once every 6 minutes are used. To minimize heating and cooling requirements, air removed from work spaces is sometimes recycled (rather than being exhausted to the atmosphere) after it has been sufficiently cleaned by fabric filters to meet occupational hygiene standards. In contrast to the practice of maintaining work spaces at slight negative pressures in order to alleviate emissions through windows, doors, and structural leaks, the production areas of these mills are maintained at a slight positive pressure relative to the outside environment. Plant operators consider this necessary to provide a temperature and humidity seal for the work areas. Accordingly, it is important to control strictly the emission of asbestos at the source in order to prevent atmospheric discharge through structural openings at these facilities. Control methods for asbestos emissions that accompany unloading, transporting, warehousing, transporting to bag-opening areas, and the opening and dumping of asbestos contained in bags are discussed in Section 3.3.2.

Air-ventilated partial enclosures and dust capture hoods of the high-volume, low-velocity type are effective in controlling emissions from openers or willows. Also, emissions can be reduced by opening and dumping bags in a centralized, isolated area and then conveying the fibers for automatic charging into feed bins of the opener.[25]

In blending operations, the use of automatically preweighed quantities of the various fibers that are ejected onto conveyor belts and transported to blenders provides emission control by comparison with the previous practice of manual layering and piling in open spaces.[25] An oil emulsion is commonly applied to fibers prior to blending;[25,26] it has been reported that the sole purpose of application of the emulsion is to facilitate dust suppression.[26] Drum mixers have been totally enclosed for dust control.[26]

It is possible to pneumatically convey fibers directly from blending processes to feed hoppers of carding machines and reduce asbestos emissions from the corresponding manual operations.[25] The operator must "overblend" in order to compensate for the tendency of the fibers to separate while being conveyed. Most carding machines are equipped with air-exhausted partial enclosures, or dust-capture hoods.[25] The designs are compromises between thorough dust removal and minimum extraction of longer-fiber stock from the material undergoing carding. Hooding of both the high-volume, low-velocity and the low-volume, high-velocity types is in use. The latter design is a refinement of the former and is reported to collect approximately 0.0025 pound of dust per 100 cubic feet of air handled.[26,27] Further, the feasibility of completely enclosing cards to control asbestos emissions has been investigated.[26] Carding machines can be cleaned with a revolving brush, fitted with air suction, which is passed across the card cylinder.[26] As far as emissions to the mill work space are concerned, this technique is markedly superior to stripping with a jet of compressed air.

The application of dust-capture hoods to control emissions from beaming machines is being investigated.[26]

Spinning frames are not frequently fitted with dust control devices. Machines are now available, however, that stop the rotation of a spindle when an end of yarn breaks; emissions from the whipping of the loose end are therefore eliminated. In a British installation, a spinning frame has been outfitted for emission control by shielding long sections of the frame from the floor upward and ventilating the enclosure. One section behind the winding spools remains unshielded to provide for air entrance across the spools and oscillating yarn. A long baffle plate shields the spool area from the working aisle and serves as a type of high-volume, low-velocity hood to collect and prevent dispersal of dust as air is drawn across, above, and below the plate.[25]

In some asbestos textile mills, emissions from weaving looms have been controlled to the extent that weaving is the cleanest of all textile operations.[26] Control methods include dust-capture hooding and the substitution of wet weaving for the original dry processes.[26] Wet weaving is carried out by passing the warp through a trough of water on the loom, by spraying water on the frame, by spraying water on the yarn, or by a combination process.[27] A primary requirement of dust capturing hoods and enclosures is that they incorporate convenient accessibility to repair frequent thread breaks.[25]

Figure 3-25 illustrates a dust-capture hood of high-volume, low-velocity type that is applicable to the control of asbestos emissions from a loom; dust is collected from the top of the heddle frame and shuttle areas. Hinged windows of transparent plastic at the front permit visual observation and ready accessibility to the shuttle-heddle frame area. A dust settling pan and ventilated hopper are located at the lower rear portion of the loom.[25] This particular configuration does not catch dust that settles downward from the center portion of the loom, but this emission is subject to control. The degree of emission control attainable by the hooding of a loom can be evaluated from published results of a decrease from 14 to 0.5 pound per week of dust and fiber collected from under a loom with, respectively, no emission control and extensive hooding.[26] Braiding operations can either be hooded or carried out with wet yarn to provide emission control.

3.3.8 Asbestos-Asphalt Paving Compounds

When asbestos is added to asphalt paving compounds in the amount of 2 to 3 percent by weight, the quantity of asphalt in the mix can be increased by between 30 and 100 percent to yield a material containing from 7 to 11 percent by weight of asphalt.[28] The result is an improved pavement overlay with increased cohesion and abrasion resistance and decreased water permeability and material embrittlement.[28] This type of paving has been applied extensively in California, where it is estimated that more than 20 percent of

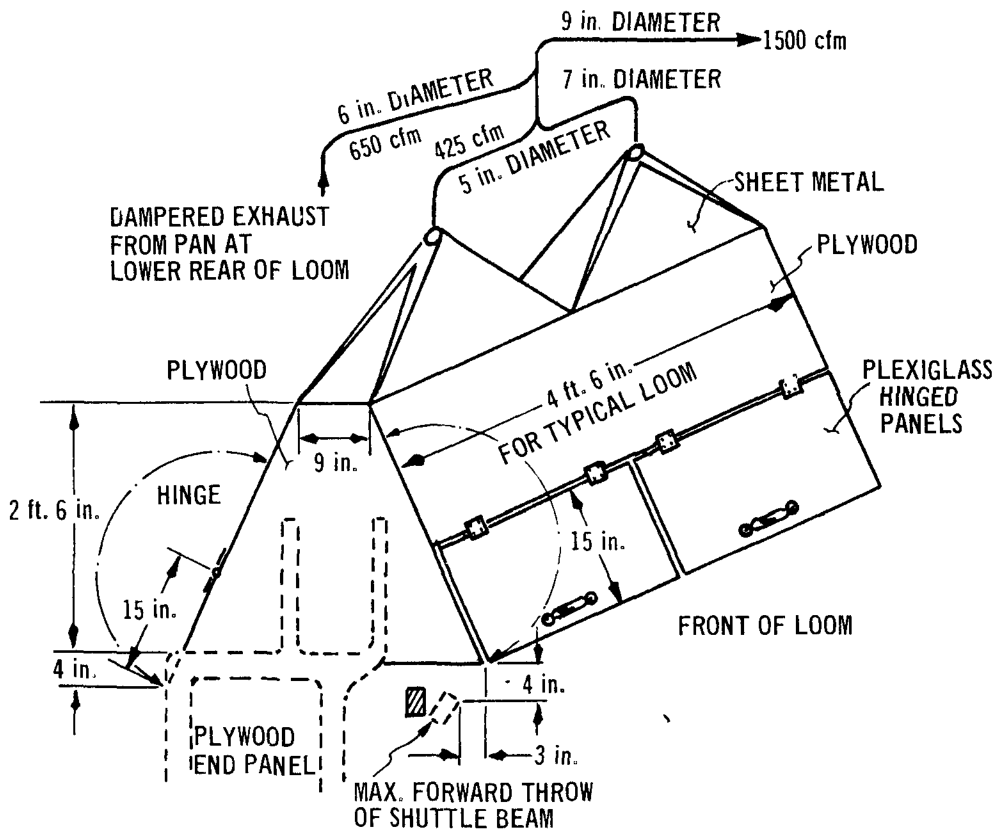


Figure 3-25. Dust capture hood for dry weaving loom.[25]

the population resides in proximity to asbestos-asphalt paving; other applications include the New Jersey Turnpike and the Trans-Canadian Highway.[28]

Figure 3-26 illustrates the mixing section of a manufacturing plant for asphalt paving compounds. The typical practice for the introduction of asbestos into a mixture includes the manual opening of bags of asbestos, discharging of asbestos into the receiving hopper for limestone and flyash, conveying to a storage bin, and discharging into the pug mill for blending with other components of the formulation. The laying of asbestos-asphalt paving compounds is by standard paving equipment.

3.3.8.1 Emissions

In the manufacture of asbestos-asphalt paving compounds, the handling of bags of asbestos, emptying of asbestos into receiving hoppers, and the discharge of dry fibers into storage hoppers, weighing devices, and mixers are potential sources of asbestos emissions. No conclusive data have been presented to ascertain the extent to which asbestos emissions accompany the gradual and continual wearing away of asbestos-asphalt road surfaces.

3.3.8.2 Control Techniques

The enclosure of bag opening and emptying areas, storage bins, conveyor systems, and mixers can provide control of atmospheric emissions of asbestos from manufacturing facilities for asbestos-asphalt paving materials. Also the use of pulpable bags could reduce emissions. In cases where it may be desirable to maintain relatively low asbestos concentrations within an enclosure by providing dilution ventilation (such as in a bag-opening area) or in cases where air displaced by the addition of solid material must be vented to the atmosphere, emissions can be controlled by treating exhaust streams by fabric filters.

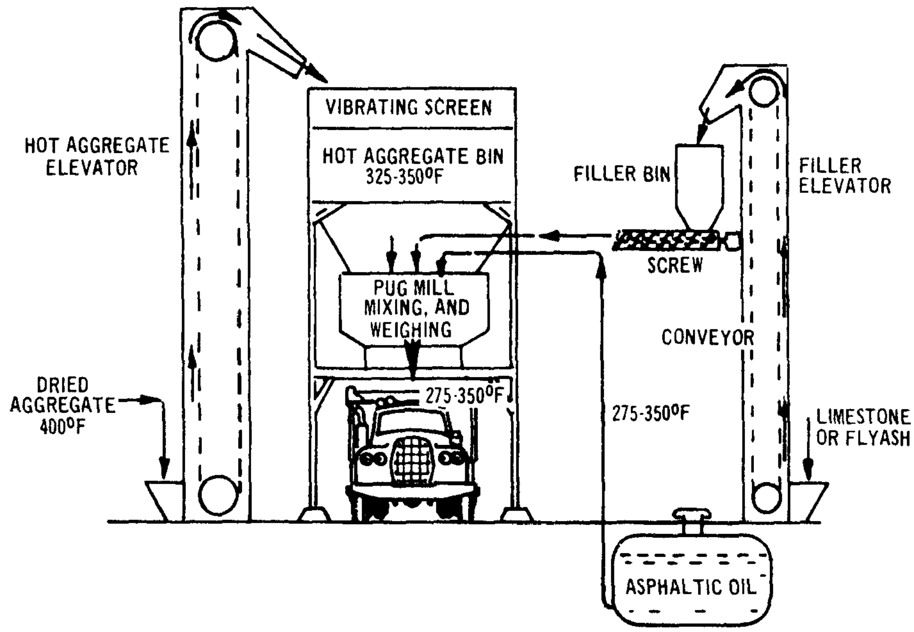


Figure 3-26. Mixing section of manufacturing plant for asphalt paving.[29]

3.4 END USES OF PRODUCTS CONTAINING ASBESTOS

3.4.1 Sprayed Asbestos-Containing Insulation Materials

Spray application of asbestos-containing insulation materials is used extensively for fireproofing of steel-reinforced structures. Depending upon the particular formulation of sprayed material, acoustical insulation can be simultaneously provided. Thermal insulation for high-temperature equipment such as chemical process vessels, steam turbine shells, furnace walls, and boiler walls is also installed by spraying. Requirements for the two applications differ in that the layer of insulation must withstand thermal cycling in insulating high-temperature equipment as opposed to the design for a single thermal shock in the fireproofing of steel structures. Other asbestos-containing materials applied by spraying are specifically formulated to provide either ambient temperature thermal insulation or acoustical insulation.

The spraying technique has been developed to accommodate those situations in which the presence of irregular shapes and large areas would lead to difficulty and excessive cost in insulating by conventional block, mat, and hand-troweling techniques. Some types of sprayed insulation materials can be tamped prior to drying to produce a decorative finish. A coat of sealer or paint can be applied either for decorative purposes or for improving resistance of the surface to the loss of material by abrasive action.

These spray-applied insulation materials contain asbestos fibers, a water-setting binder such as cement, and in some cases other fibers such as glass wool or mineral wool. Amosite, crocidolite, and chrysotile in amounts from 5 to 80 percent by weight are used; the majority of formulations contain either chrysotile or amosite. The materials are usually dry-mixed at an off-site manufacturing facility and are delivered to a spraying location in kraft bags of approximately 50-pound capacity.

Two types of spraying processes in commercial use are shown in Figure 3-27. For cementitious spraying, the bags of premixed insulating material are emptied into the hopper of a spray machine; the material is mixed with water to form a slurry; and the slurry is pumped to the point of application, which can be hundreds of feet removed from the mixing operation. A jet of compressed air

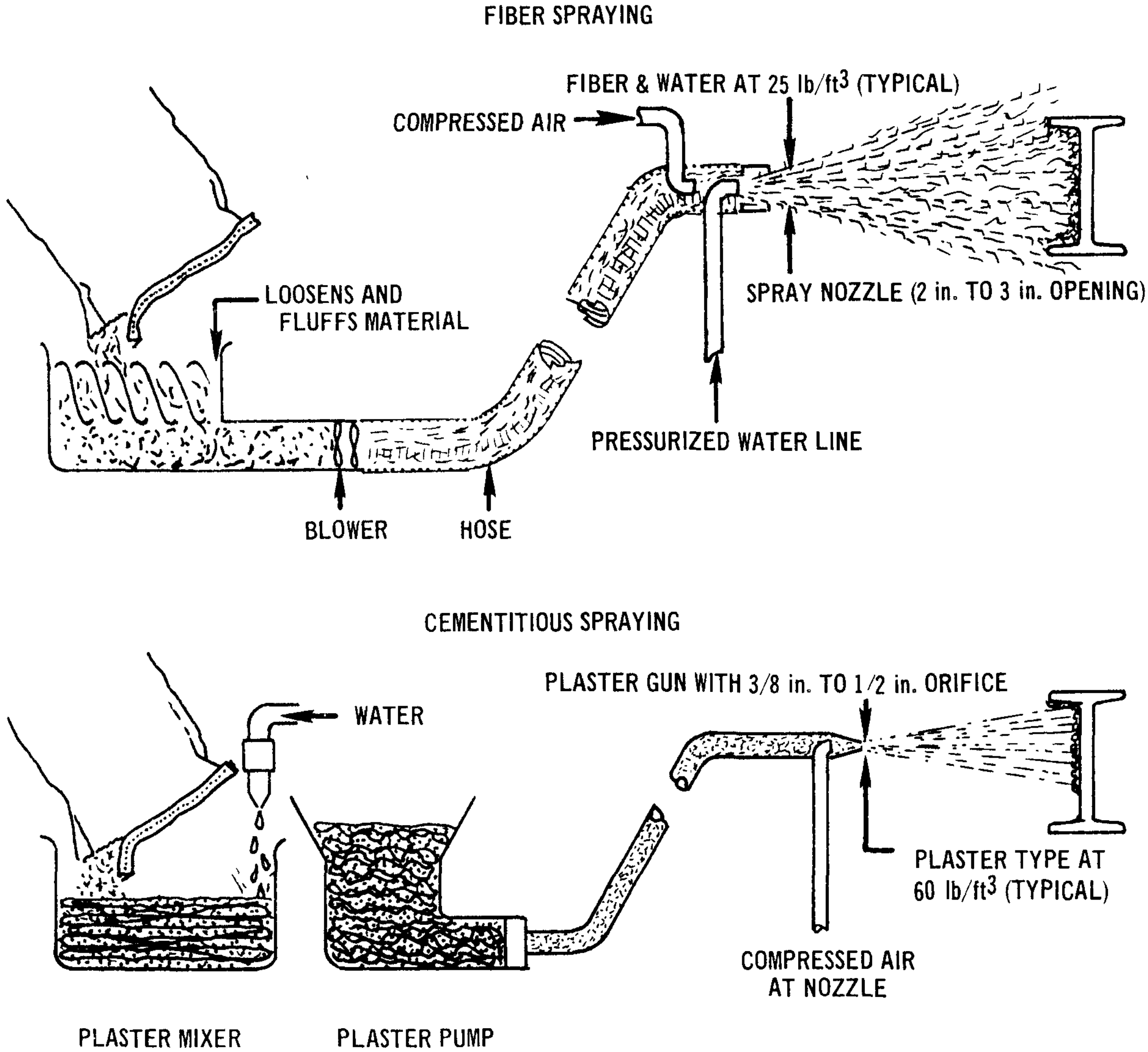


Figure 3-27. Spray processes for asbestos-containing insulation materials.

is emitted at the spraying nozzle together with the slurry to assist in dispersing the insulating material into a spray and propelling it onto the surface to be insulated. In fiber spraying, the second type of application, the bags of fibrous insulating material are likewise manually emptied into the hopper of a spray machine, but the insulation is pneumatically conveyed in a dry condition to the spraying nozzle. The insulation passes from the spray machine hopper to carding brushes, which perform a combing operation, and then to a blower, the impeller of which forces the material through a feed hose that supplies the spray nozzle. A compressed-air jet atomizes water supplied to the nozzle and facilitates wetting of the insulating material either within or immediately outside the outlet of the nozzle, depending upon the particular design.

The spray nozzle is typically held 12 to 24 inches away from the surface to be insulated. Insulation is often applied in more than one layer and to a thickness of more than 2 inches.

3.4.1.1 Emissions

Asbestos-containing insulation is frequently sprayed in spaces directly open to the atmosphere. Asbestos spray fireproofing applied to buildings during construction, particularly high-rise structures in large metropolitan areas, is the most extensive single use of this type. Also, sprayed high-temperature thermal insulation is frequently applied to such equipment as steam turbines and chemical process vessels that are not housed within structures.

Visible atmospheric emissions of asbestos-containing particulates resulting from the spray application of asbestos insulation are not uncommon. For example, emissions accompanying the spray fireproofing of structures in New York and other metropolitan areas have been described as "extensive snowfalls of asbestos-containing material."[30] In some cases, these emissions are traceable to the incomplete wetting of dry insulating material either interior to, or slightly downstream from, the outlet of a fiber spraying nozzle. Further, both the cementitious and fiber spraying techniques produce large quantities of wet insulation that does not adhere to the target surfaces. A portion of this wet material can be emitted directly to the atmosphere external to the work space, and large quantities settle onto surfaces of the work space beneath the sprayed area. The latter deposits can become secondary sources of asbestos emissions via dispersal by vehicular and human traffic in the work area, particularly if the wet insulation dries before it is removed for waste disposal.

When asbestos-containing insulation is applied by spraying techniques within structures that are essentially shielded from the external atmosphere, forced gas streams exhausted from the structures and incidental discharges of work-space ventilation air through windows and doors are potential sources of atmospheric asbestos emissions. In the course of transporting bags of dry spraying mixture to a job site and during the handling, stacking, and storing of these in a work area, asbestos can be emitted to the work space from punctures through bags and from bag closures that are not dust tight. A non-dust-tight type of bag seal is formed, for example, by stitching together the end of a bag without initially folding over the end and sewing through four layers of composite packaging material. The manual opening of bags of spraying mixture and the subsequent dumping of the contents into the hopper of a spray machine are potential emission sources that are similar to those encountered in the preliminary steps of manufacturing processes (see Section 3.3.1). Emissions produced by the spraying process and potential secondary emissions from wet oversprayed material have been cited above. Potential emissions that can be generated by the disposal of overspray material and of empty insulation-mixture shipping bags are discussed in Section 3.5.1.

3.4.1.2 Control Techniques

Initial attempts to control excessive atmospheric asbestos emissions from the spray fireproofing of buildings under construction were directed toward the adoption of good housekeeping procedures at spraying sites and the containment of potential emissions within the structures. This method of emission control was generally recommended by the spray insulation industry.[31]

The open perimeters of entire floors of new buildings have been shielded with tarpaulins and plastic sheets for the purpose of containing emissions from spray fireproofing. Further, recommended work practices include an initial cleaning of floor areas and the removal of portable objects (or the covering of such articles with dust-impervious tarpaulins or plastic sheets) to facilitate cleanup of spraying areas and thereby reduce potential emissions from this phase of waste disposal.

The development of spray fireproofing and high-temperature thermal insulating materials that contain little or no asbestos has been undertaken in direct response to the need for control of asbestos emissions. One cementitious type of spray fireproofing compound containing no asbestos is now in use This substitute compound in applied in the same manner as the previous asbestos--containing material, and equivalent fire resistance ratings approved by Underwriters' Laboratories, Inc., for a large number of construction systems are attained with comparable thicknesses of the two materials. Several asbestos-free spray fireproofing materials of fiber type are also available, and other manufacturers of asbestos fiber spray fireproofing have asbestos-free substitute materials in a state of active development. In addition, several asbestos-free, fiber-type products are marketed for application as high-temperature sprayed thermal insulation.

If sprayed asbestos insulation is employed within enclosed structures, potential asbestos emissions to the atmosphere can be controlled by sealing all openings through which contaminated air could be discharged to the exterior of the structure. In situations requiring ventilated spraying areas, fabric filters can clean the exhaust air prior to discharge to the atmosphere. Appropriate control measures can limit emissions to the work space, but the practical implementation of these may result in excessive labor costs in comparison with the use of an asbestos-free material that might not require such stringent control practices. Suggested techniques for controlling potential work space emissions are discussed in the following paragraphs.

To control asbestos emissions from packaged spray insulation materials, the bags should be factory sealed with a dust-tight closure and should possess sufficient strength to withstand normal handling without damage that would expose the asbestos. Minor bag punctures can be promptly sealed with masking tape; whereas, more extensively damaged bags can be protected by a plastic slipover bag that can be sealed dust tight.

The airborne disperson of emissions that accompany the manual opening of bags and the charging of dry insulation material into the hopper of a spraying machine can be lessened by enclosing and ventilating the immediate work space. Because it is not necessary to relocate the hopper as insulation is applied at various locations within a building, the opportunity exists for conveniently employing a portable high-volume, low-velocity capture hood in conjunction with a gas-cleaning device to control emissions. A hood configuration of this type, applied to a bag opening and conveying station, is shown in Figure 3-12. Proper technique by the operator in opening and emptying bags can minimize the amount of emissions that must be controlled. Empty bags should be immediately placed into dust-tight containers and then disposed of, as indicated in Section 3.5.2.

As an alternative to fiber spraying processes that incompletely moisten the insulating material, the use of cementitious spraying can be considered as a control technique for the reduction of asbestos emissions during spraying. If fiber spraying is employed, the atomized water spray should be in operation prior to passing insulating material into the nozzle and should be removed from operation only after the fiber supply is cut off. Otherwise, the ejection of dry insulating material from the nozzle yields asbestos emissions. For either type of spraying, an initial cleaning of floor areas and covering of exposed articles in the spraying area facilitates cleanup and reduces potential asbestos emissions. The enclosure of a spraying area with tarpaulins or plastic sheets can, when properly applied, significantly reduce the spread of airborne asbestos to other areas of the work space during both spraying and cleanup. Proper implementation is seldom practicable in terms of labor cost, however.

In collecting asbestos-containing wastes for subsequent disposal, wet overspray should be removed from floors and other surfaces, and dry wastes should be vacuumed from tarpaulins as soon as no further material is being deposited. The waste materials should be wetted before sweeping.

Particular attention should be given to the removal of asbestos-containing wastes subject to entrainment by ventilating air, such as material in the plenum space of a building or in ventilation ducts. Coating the sprayed insulation with a surface sealant provides additional protection against the possibility of emissions through abrasion of the material.

3.4.1.3 Control Costs

The cementitious and fiber spray processes for fireproofing structures with asbestos-containing materials are commercially competitive. The installed cost for 500,000 board feet of fireproofing is approximately $0.13 per board foot of applied material when the density of the cured coating is 12 pounds per cubic feet.

A non-asbestos-containing substitute for a cementitious spray fireproofing is currently marketed at a material cost, per unit weight, equal to that of the original asbestos spraying mix. The yield of the substitute material, as well as the fire rating (where approved) of a given thickness of coating, matches that of the asbestos-containing material. The method of application is unchanged by the elimination of asbestos. Consequently, the installed cost of the substitute fireproofing is the same as that of the original material.

The material cost of one asbestos-free fiber spray fireproofing compound is approximately equal to that of the asbestos-containing material that it replaces. The exclusion of asbestos from several other fiber spray fireproofing formulations, which are undergoing development, is estimated to result in an increase of 10 to 15 percent in material costs. The method of application and the fire rating attainable with a given thickness of applied coating of these substitute products are not significantly different from those of the original asbestos-containing systems of protective coating.

3.4.2 Field Fabrication of Products Containing Asbestos

Insulating materials that contain asbestos as either a primary or secondary ingredient are frequently applied on-site by techniques other than spraying. Typical examples are the insulation of pipes, boilers, breechings, turbines, and industrial furnaces. The chrysotile variety of asbestos is usually employed; sheets and boards composed of crocidolite are not well suited for thermal insulation.[19]

Preformed sections or blocks are available as molded asbestos, molded calcium silicate-asbestos, molded 85 percent magnesia, and molded high-temperature insulating block. These materials can also maintain cold temperatures, but a surface sealant such as asphalt, silicate or cement must be used to keep the insulation dry.[19] The widely used, calcium silicate insulation contains approximately 10 percent asbestos fiber, which serves as a binding and reinforcing agent; the final product contains approximately 10 percent solid material by volume.[19]

To fill crevices between preformed sections and to insulate extremely irregular shapes, powdered material of similar composition is mixed on-site into a slurry and applied by hand trowel. Typical materials are calcium silicate asbestos cement, hard-setting asbestos cement, and asbestos skinning plaster.

Asbestos-cement products, such as siding shingles, building boards, and drain pipes, often require cutting and trimming operations during field fabrication. The surfaces of these products are less susceptible to dusting and surface abrasion than are most insulating materials.

Millboard,[19] which is a heavy form of asbestos paper, and flexible asbestos paper are examples of insulating materials that incorporate asbestos as a major component. Asbestos air cell insulation is a sandwich structure of corrugated asbestos paper and asbestos-cement sheets. Other asbestos products that are frequently installed in the field are asbestos blanket, rope, tape, yarn, and sealing compounds.

3.4.2.1 Emissions

The storage, handling, and transportation to fabrication sites of both asbestos-containing thermal insulation products and products that contain unbound asbestos present opportunities for asbestos emissions.[21,32] Cartons and bags are subject to being unsealed and broken open. Also, the abrasion and breakage that sometimes accompanies the handling of individual unpackaged units of material can produce emissions.

Significant amounts of asbestos-laden dust are produced during (1) the sawing, cutting, and sanding of pipe and block insulation to fit the contours of specific equipment; (2) the wiring and banding of insulation and the application of jackets and facings to insulation;[31] and (3) the transfer of loose mixtures of materials from bags into hoppers and the subsequent mixing into a slurry application by troweling (see Section 3.4.1.1).

The exposure of material fragments, such as trimming scrap, broken wastes, and spillage from containers, to traffic aisles of the job area and to the attendant further disintegration by human and vehicular movements is a significant source of dust emissions.[32] The consolidation and packaging of these wastes for disposal can also produce asbestos emissions.

3.4.2.2 Control Techniques

Asbestos emissions resulting from the transportation of materials to fabrication sites can be minimized by protecting cartons and packing bags from rupture. When the stacking of molded products onto vehicles is likely to abrade or fracture away small pieces of material, the use of either fully enclosed vehicle bodies or sealable containers can limit emissions.

The following recommended techniques have been applied to the control of asbestos emissions from the on-site fabrication of asbestos-cement products and asbestos-containing insulation materials:

1. Isolation of work area from exterior environment by installation of dust-impervious tarpaulins or plastic sheeting.
2. Collection of refuse from sawing, drilling, and sanding operations at the source of emissions.
3. Implementation of efficient housekeeping practices.

The effectiveness of the first measure is diminished by the need for supplying some degree of ventilation for workers' comfort and by the inherent difficulty of sealing around irregular shapes, the exterior walls of buildings under construction, and exterior operations. Low-volume, high-velocity hoods that capture the wastes produced by stationary power tools are described in Section 3.3.2. This method of effectively collecting asbestos-laden dust at the source of emission has also been incorporated into portable cutting tools. Figures 3-28 and 3-29 illustrate this type of device fitted, respectively, to a portable hand saw and to a portable electric drill, the required suction is

Figure 3-28. Dust capture device fitted to portable hand saw.[33] (Courtesy of Johns-Manville.)

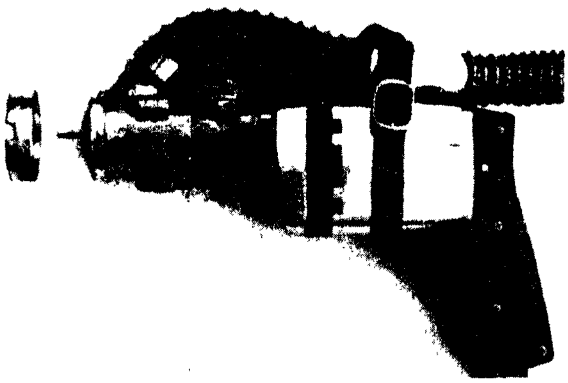


Figure 3-29. Dust capture device fitted to portable drill.[33] *(Courtesy of Johns-Manville)*

readily supplied by an industrial vacuum cleaning system. The prompt cleanup of trimmed wastes, broken material fragments, and spillage from containers minimizes further disintegration, airborne entrainment, and creation of secondary emission sources such as dispersion from workers' clothing. Tightly sealing waste containers should be conveniently accessible; vacuum cleaning devices are recommended for the removal of small particles and dust. In the absence of vacuum cleaners, the watering of wastes prior to sweeping and shoveling can be an effective control measure. The disposal of asbestos-containing wastes is discussed in Section 3.5.

In an effort to control emissions from the opening and dumping of bags of asbestos insulating cement or loose, dry insulating materials and also from the subsequent mixing of those materials with water to form a slurry, it has been proposed that mixing take place within the shipping bag.[34] Water is injected into a polyethylene bag through a narrow sleeve, and the contents are kneaded into a wet mixture prior to removal from the container.

3.4.3 Friction Products

The automotive and heavy equipment industries are the major users of asbestos friction products.[19] In 1968, new passenger and commercial motor vehicles manufactured in the United States accounted for 9,913,000 sets of brake linings, which contained an average of 3 pounds of asbestos per set.[35] The yearly number of sets of replacement brake linings can be gauged by considering that 1 trillion vehicle-miles were traveled in 1968 in the United States[1] and that an average lifetime for brake linings is 27,500 miles. Further, it is estimated that between one and two sets of asbestos-containing clutch facings are consumed during the lifetime of the average vehicle equipped with a manual clutch.

The principal types of asbestos-containing friction products are molded, woven, or extruded. Chrysotile asbestos (30 to 60 percent of product) is mixed (or asbestos cloth is impregnated) with asphalt, drying oil, synthetic resin, or rubber. Chrysotile is preferred over crocidolite because of better heat resistance and less severe wear against metal surfaces.[19]

Friction materials containing asbestos are also used in the pads of disk brakes, for clutch facings in automatic transmissions, and for brake blocks for heavy-duty trucks, earth-moving equipment, elevators, and other industrial applications. The percentage of domestically produced motor vehicles equipped with disk brakes has increased from 2.9 percent in 1966 to 11.2 percent in 1968.[35] Additional increases in the fraction of vehicles equipped with disk brakes will affect the types of operations carried out during replacement of motor vehicle brake linings.

3.4.3.1 Emissions

During the replacement of drum-type brake linings on motor vehicles, the grinding and trimming operations required for individual fitting are potential emission sources of asbestos fibers. Based on an assumed loss of 0.05 percent of brake lining asbestos content to the atmosphere during grinding and fitting, asbestos emissions from the fitting of brake linings were estimated to total 190 tons in 1968.[23] The analogous grinding operations that are performed in friction product manufacturing plants are known to yield asbestos fibers of similar physical form to those that have been associated with adverse health effects.[36] Since disk brake pads are not contour ground as drum brake linings are, the current trend to disk brakes should reduce asbestos emissions.

As brake linings and clutch facings rub against their mating bearing surfaces in the course of usage, particles of the lining material are abraded. These particles can be partially trapped in the housings of manual clutches and in brake drums; the remainder can be emitted directly into the atmosphere. The latter emissions are treated as a problem in mobile source air pollution control and are outside the scope of this study.

Because extremely high temperatures can result from the sliding of brake linings and clutch facings against the corresponding mating surfaces, the question arises as to whether the asbestos that would otherwise be contained in the particles released from the friction materials has been thermally degraded. One set of tests of automobile, bus, and truck drum brakes and clutches has shown that, except under conditions of very severe usage, the majority of the freed asbestos has been thermally degraded.[36] For example, most of these samples of released material from automotive brakes contained less than 1 percent asbestos as compared with 50 percent in the original lining formulation.[36] This residual amount, however, is not inconsequential relative to air pollution control. Further tests are needed to evaluate emissions from disk-type brakes.

In the course of servicing and overhauling motor vehicle brakes and manual clutches, the accumulated asbestos-containing dust is frequently dislodged from drums and housings by directing a compressed air jet against the deposits.[37] Depending upon the servicing location, this results in airborne asbestos emissions either to the work space or directly to the atmosphere.

3.4.3.2 Control Techniques

Asbestos emissions accompanying the grinding and trimming of replacement brake linings at the site of installation and fitting are presently uncontrolled at most sites. The incorporation of low-volume, high-velocity dust-capture hoods (see Section 3.3.2) into grinding equipment is feasible and can provide an effective method for controlling these emissions.[18]

The removal of asbestos-laden dust from brake drums and from housings of manual clutches by the compressed-air-jet method produces uncontrolled emissions. The dislodging and collection of this waste material at the source by operating a brush connected to an industrial vacuum cleaner as a low-volume, high-velocity dust capturing and collecting device has been evaluated.[37] This control technique reduced personal exposure to fibers larger than 1 micrometer in diameter by approximately 75 percent.

3.5 DISPOSAL OF ASBESTOS WASTE MATERIALS

Potential waste materials containing asbestos are produced during the mining and milling of asbestos ores and in the manufacture and use of asbestos-containing products. The form of asbestos in these wastes ranges from asbestos bound in relatively large rock masses or in such manufactured products as asbestos-cement pipe and reinforced plastics to small-diameter, readily dispersed asbestos fibers that are removed by gas-cleaning devices or are produced in the milling of asbestos ores.

In mining operations, large quantities of asbestos ore are sometimes rejected at the mine site because either the concentration or the form of dispersal of the asbestos renders recovery uneconomical. The lower limit for profitable recovery of chrysotile asbestos from massive deposits of serpentine rock is a concentration of approximately 3 percent.[1]

The richness of the non-massive Coalinga asbestos ore permits larger rocks to be discarded in screening operations at the mine. Further, in most surface mining operations, it is necessary to remove overburden that contains small concentrations of asbestos in order to expose the ore deposits.

The milling process for asbestos ore eventually discards, from screening operations, finely divided rock in combination with small amounts of the shorter asbestos fibers. Also, very short asbestos fibers that are collected by gas-cleaning devices after entrainment during the air aspiration process for separating the longer fibers from crushed ore sometimes require disposal.

Asbestos mills and plants that manufacture asbestos-containing products frequently use fabric filters and other gas-cleaning devices to remove asbestos fibers from the ventilation air of the entire work space as well as from process gas streams. The application of asbestos products to end uses is accompanied to a lesser extent by similar filtering devices: for example, portable vacuum cleaning machines are often used to remove settled dry asbestos wastes. In each of these instances, the collected material must be handled again as it is periodically removed from the filtering device.

Asbestos fiber and certain end-use asbestos products, such as spray insulating compounds, are shipped in paper or plastic bags. Because appreciable amounts of asbestos dust are retained on the emptied bags, a method of disposal that minimizes atmospheric emissions is needed. The manufacture of asbestos-cement and asbestos paper produces a mixture of asbestos fibers and water; the removal of the asbestos to prevent a water pollution problem should be accomplished in such a way that atmospheric emissions are avoided. Scrap and rejected material containing bound asbestos from the manufacture of such products as vinyl-asbestos tile, asbestos-cement, asbestos paper, and asbestos reinforced plastic require disposal. The overspray from application of sprayed asbestos insulation materials must be consolidated and packaged for disposal.

Demolition of residential and commercial buildings has been major in scope in recent years in most American cities, as the result of urban renewal and other massive projects. Structures subject to demolition are frequently sources of asbestos-containing waste materials. These wastes include friable materials, such as pipe and boiler thermal insulation, and bound materials, such as asphalt-asbestos floor tile, vinyl-asbestos flooring products, asbestos-cement roofing and siding shingles, and acoustical ceiling tile. Future demolition operations will also be concerned with the disposal of waste asbestos spray fireproofing. Disposal of asbestos-containing wastes during demolition can be either a selective stripping of the materials from a structure or the fragmentation of the entire structure and contents as a unit.

3.5.1 Emissions

The exposure in open-dumping sites of such diverse wastes as asbestos mine overburden, oversized masses of screened asbestos ore, asbestos mill tailings, emptied asbestos shipping bags, and the consolidated overspray of asbestos-containing insulation provides an opportunity for the entrainment and widespread dispersion of asbestos fibers into the atmosphere. Atmospheric emissions can also result from the open disposal of the material collected by gas-cleaning devices, from the open disposal of scrap pieces of insulating materials and asbestos-cement products that carry surface deposits of asbestos dust produced by fabrication and field installation operations, from the weathering in open dumps of even those materials in which asbestos is originally present in a bound condition, and from the disposal of emptied shipping containers for asbestos.

The properly managed disposal of emptied bags in a dump is thought to generate less emissions than the incineration of such bags; however, the degree of thermal degradation of the asbestos during incineration has not been fully evaluated.

Careful handling is required to prevent atmospheric emissions as loosely bound asbestos-containing materials, such as the particulates retained by a gas filtering device or the waste from the application of sprayed insulation, are loaded into temporary or permanent containers to facilitate eventual disposal.

Loosely bound asbestos dust on the surface of waste materials located in a work area can be entrained into the air and dispersed by room currents. Spreading and eventual emission can also result from contact of the body and clothing with this dust. Asbestos emissions are reduced by minimizing the period of exposure of the wastes to the working environment. Trimmed pieces of asbestos-cement pipe, vinyl-asbestos floor tile, and asbestos-containing pipe insulation are examples of these waste materials.

As noted in Section 3.1.1, the use of asbestos mine and mill wastes for the surfacing of roadways can lead to the emission of asbestos as the roads are constructed and as the passage of vehicles generates air entrainment currents and further disintegrates the waste material.

The fragmentation of waste material during demolition operations is an inherently dust-producing process. Asbestos materials are deliberately broken apart when a structure and its contents are demolished by drop-ball cranes or explosives, but there can be a significant quantity of material breakage and dust generation even during the selective stripping of asbestos-containing materials from a structure prior to its demolition. The handling and loading of demolition wastes for transportation to a disposal site are likewise potential sources of large quantities of airborne dust. The ultimate disposal of asbestos demolition wastes in open dumps can yield significant atmospheric asbestos emissions.

3.5.2 Control Techniques

Potential emissions associated with the removal of dry, asbestos-containing materials collected by gas-cleaning devices can be controlled by providing a dust-tight sealing arrangement between the collector hopper and the disposal bag or bin. For example, clear polyethylene bags of appropriate strength can often be banded around the hopper discharge.[28] The resultant clear visibility of the level of material in the waste container assists in sealing and removing the bag from the hopper nozzle with a minimum of emissions. When wastes are collected by smaller, portable vacuum cleaning equipment, single-service bags can be employed to eliminate the necessity for transferring the waste to an intermediate container prior to disposal. Asbestos-containing sludge from wet collectors should be drained into moisture-proof vats suitable for transporting the waste to a dumping site.

Airborne wastes generated by machining and trimming can be collected at the source of emissions by low-volume, high-velocity dust capture hoods fitted to stationary and portable power tools (see Sections 3.3.2, 3.4.2). The adoption of this control technique reduces the handling phase of waste disposal to the removal of a directly disposable dust deposit bag. When no provisions are made at the source to immediately entrain or collect trimming wastes and broken fragments of asbestos-containing materials that readily produce dust, waste receptacles with tightly fitting lids should be provided at convenient locations in the working area. If a specific type of operation generates dust emissions from the charging of a receptacle, it is desirable to provide a dust-capture hood of the high-volume, low-velocity type at the charging site to control emissions. Larger pieces of rejected, friable, asbestos-containing materials can likewise be placed into receptacles prior to eventual disposal. Emissions from emptied bags or other discarded containers of dry, loosely bound, asbestos-bearing products can be controlled by placing the containers into receptacles immediately after dumping the contents. Even though asbestos fibers are strongly bound into such products as asbestos-cement and asbestos-containing plastics, loose dust freed by machining and breakage can be carried on the surfaces of these materials. Consequently, these wastes should also be placed into receptacles reserved for asbestos disposal.

The most frequently applied asbestos emission control technique for demolition operations is the thorough wetting of the surface and, where possible, water soaking of asbestos-containing materials prior to stripping of the materials or breakup of an entire structure. The use of additional quantities of water together with enclosed conveying chutes can reduce emissions during the loading of demolition wastes into transportation vehicles. When ambient temperatures are below freezing, however, the opportunities for dust suppression by wetting of wastes are limited.

The stripping of asbestos-containing materials, particularly those which are friable, prior to the breakup of a structure is a more direct method of controlling asbestos emissions during demolition than is the application of dust control measures during the fragmentation of an entire building simultaneously with the asbestos wastes. Methods for the control of emissions generated by the field fabrication of asbestos-containing products (see Section 3.4.2.2) can be adapted to stripping operations. These methods include the adoption of good housekeeping practices, the shielding of work areas with tarpaulins, the use of dust-capture hoods, and the cleaning of dust control air streams by fabric filters.

As asbestos-bearing wastes that have been collected and consolidated undergo disposal, emphasis should be placed upon emission suppression during transportation, dumping, and repose in the dump. Wastes that are otherwise uncontained are preferably placed into dust-tight bags or other dust-tight containers for transit to the disposal location. For example, if permanent disposal receptacles are not carried to a dump site for emptying, then the contents, such as discarded bags and fragments of scrap materials, can be transferred and sealed into impervious bags for transport. This intermediate handling should be performed under a dust-capturing hood vented to a gas-cleaning device. As mentioned above, wet wastes should be transported in waterproof containers.

In all cases, transporting vehicles and reusable containers should be either wet- or dry-cleaned when dumping is completed.

If wastes are accidentally spilled in transit to a dumping site, cleanup should be undertaken as soon as possible. Extensive spills that can not be readily removed should be immediately covered or wetted to control dispersion.

Access to the face of a dump should be provided for vehicles depositing asbestos-containing wastes; to minimize the possibility of rupturing disposable containers, wastes should not be dropped long distances when unloaded. A location of waste deposition on the dump is preferred which will lessen potential emissions from subsequent movement of the wastes as additional material or a sealing covering is placed on top. Earth or, in some cases, other dry wastes can be applied as the sealing material to prevent emissions from exposure of the wastes to the atmosphere. Wet wastes and wastes containing strongly bound asbestos should also be covered with a seal; otherwise, subsequent drying and disintegration can eventually permit emissions to the atmosphere.

When disposal operations and dump management are not under the direct control of persons discharging wastes, periodic inspection of the dump site should be conducted to assure adherence to recommended practices.

Control techniques for emissions from asbestos mining waste deposits and asbestos mill tailings dumps are discussed in Sections 3.1.2 and 3.2.2, respectively.

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4. COSTS OF CONTROL BY GAS CLEANING DEVICES

Dry centrifugal collectors, wet collectors, and fabric filters are three candidate devices for application to the cleaning of asbestos-laden process gas streams. The purpose of this chapter is to present a rational methodology for estimating the installed and operating costs for these types of control equipment.

The expenditures for installation and operation of an air pollution control system can be categorized as capital investment, maintenance and operation costs, or capital charges. Within each of these categories, it is convenient to identify several types of costs:

1. Capital investment:
   - Control hardware
   - Auxiliary equipment
   - Installation
   - Engineering studies
   - Land
   - Operating supply inventory
   - Startup
   - Structure modification.
2. Maintenance and operation:
   - Labor
   - Supplies and materials
   - Utilities
   - Treatment and disposal of collected material.
3. Capital charges:
   - Insurance
   - Interest
   - Taxes.

Substantial portions of the following treatment have been excerpted from the paper of Edmisten and Bunyard.[1]

4.1 CAPITAL INVESTMENT

The installed cost of an air pollution control system includes expenditures for control hardware, auxiliary equipment, and field installation; the manufacturer's cost quotation is usually based upon an engineering study of the individual emission source. The remaining items in the category of capital investment will not be further characterized here because of their wide variance, but these can be readily incorporated as more detailed requirements of a specific installation are considered.

The purchase costs charged by manufacturers for fabric filters, dry centrifugal collectors, and wet collectors constructed of standard materials are graphically illustrated in Figures 4-1, 4-2, and 4-3, respectively. These data were obtained by adjusting the 1968 cost estimates of Edmisten and Bunyard[1] to a February 1972 basis. Efficiency of collection and throughput of process gas are the primary variables that affect purchase costs, but a precision of ±20 percent applies to Figures 4-1 through 4-3 to account for cost differences among applications to wide ranges of processes. Table 4-1 lists ranges of collection efficiencies for the control devices. When the purchase cost of a particular type of gas-cleaning device for application to a specific process has been determined by detailed analysis, the cost for a similar device of different capacity can be scaled from the equation:

$$C_2 = C_1 \left(\frac{Q_2}{Q_1} \right)^n$$

where:
- C_1 = known hardware cost
- C_2 = desired hardware cost
- Q_1 = volumetric rate of gas handling of collector for which cost is known

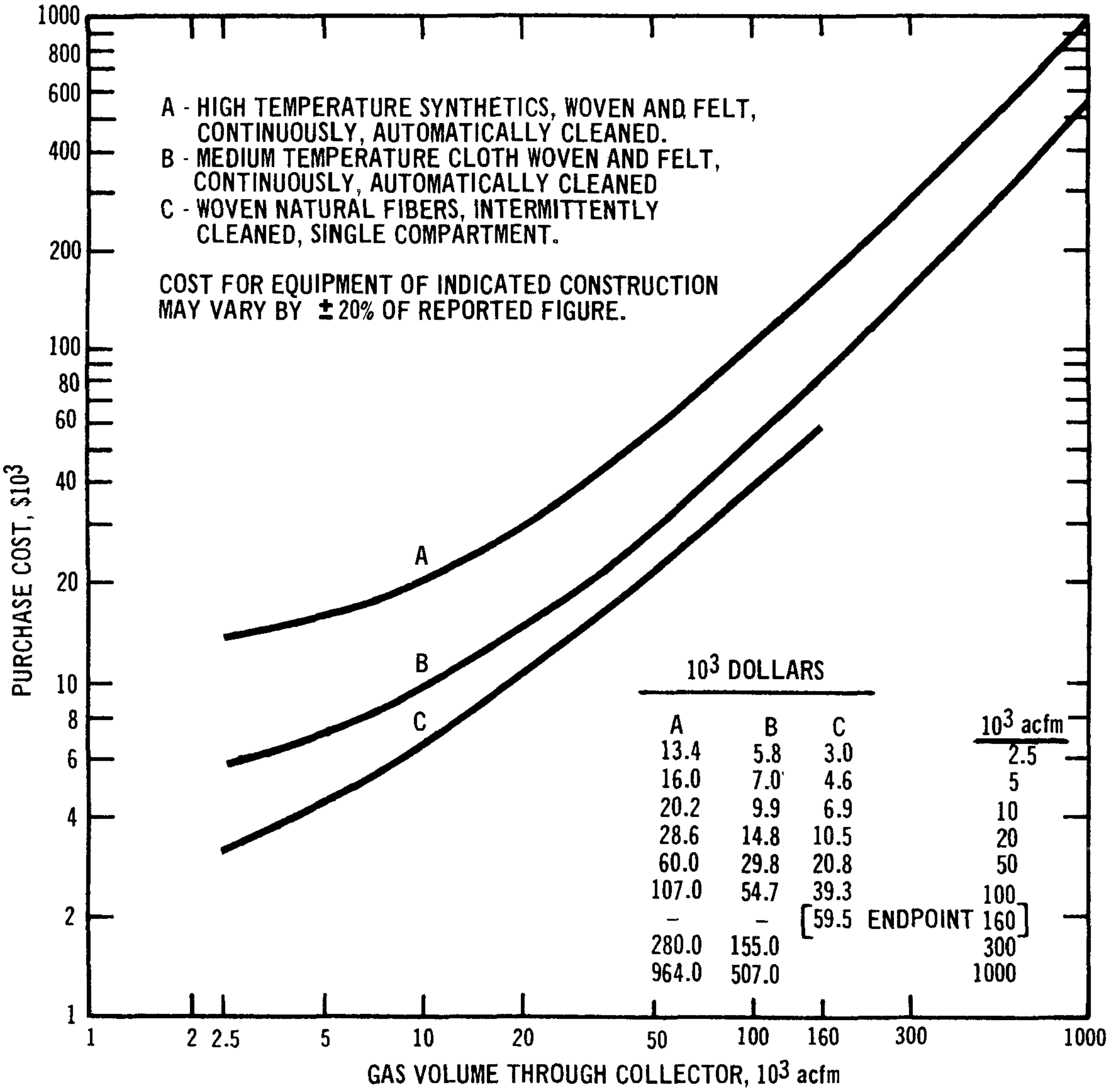


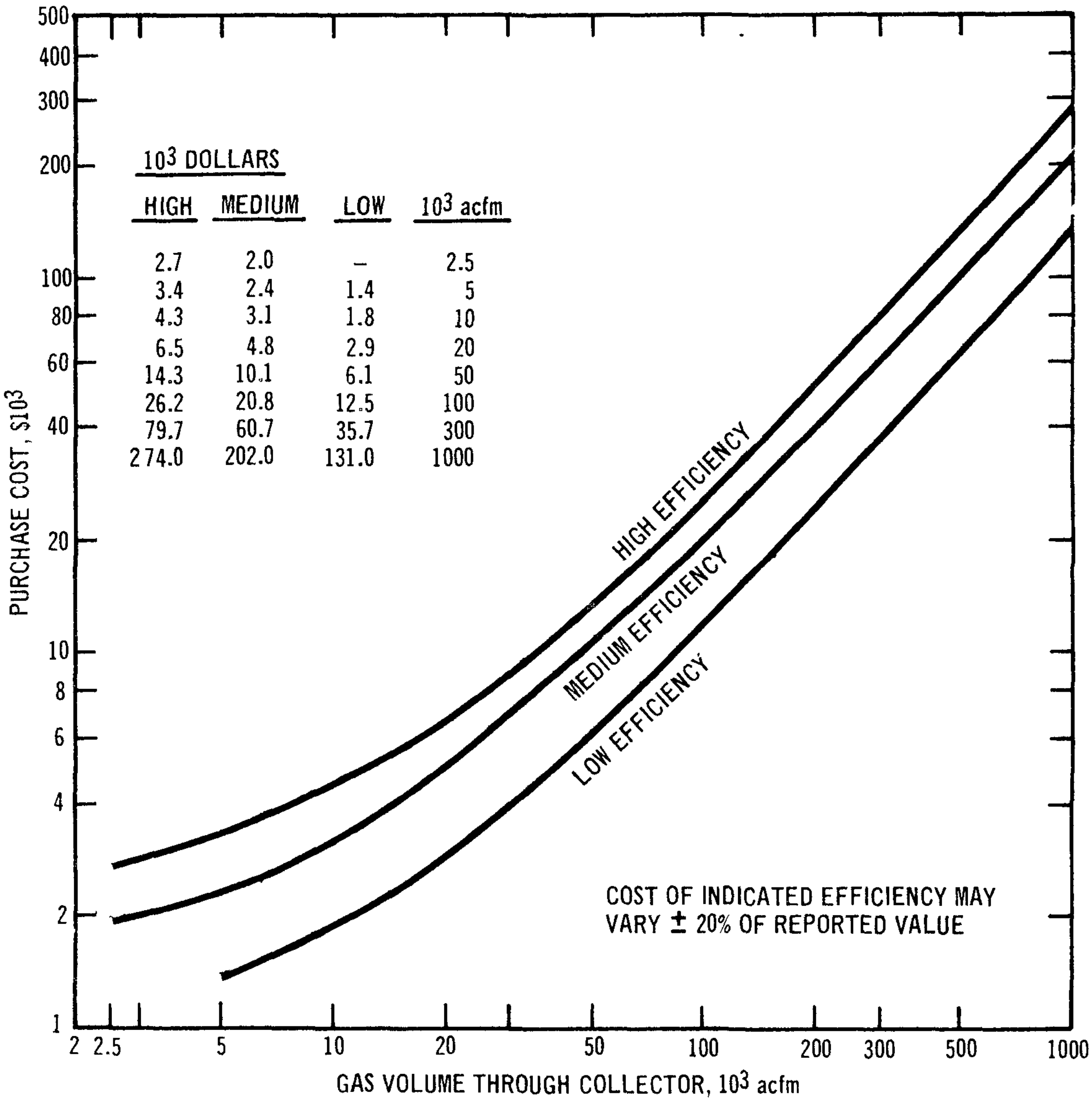
Figure 4-1. Purchase cost of fabric filters (February 1972 estimate).

Q_2 = volumetric rate of gas handling of collector for which cost is desired

n = cost-capacity factor

The cost-capacity factors for several gas-cleaning devices are tabulated in Table 4-2.

The total installed cost of an air pollution control system, including costs for control hardware, auxiliary equipment, and field installation is conveniently expressed as a multiple of the purchase cost for control hardware (see Table 4-3). Expenditures for erection, insulation materials, transportation of equipment, clarifiers and liquid treatment systems for wet collectors, and such auxiliary equipment as fans, normal ductwork, and motors are included. The low values of Table 4-3 correspond to minimal transportation requirements and to simple layout and installation of control devices. High transportation costs and more difficult layout



HIGH	MEDIUM	LOW	10^3 acfm
2.7	2.0	–	2.5
3.4	2.4	1.4	5
4.3	3.1	1.8	10
6.5	4.8	2.9	20
14.3	10.1	6.1	50
26.2	20.8	12.5	100
79.7	60.7	35.7	300
274.0	202.0	131.0	1000

Figure 4-2. Purchase cost of dry centrifugal collectors (February 1972 estimate).

and installation result in higher values; unusually complex installations such as those encountered with existing process situations lead to the extremely high values. Table 4-4 presents a detailed list of cost categories for the total installed cost and specifies those factors that determine low, typical, high, and extremely high costs.

4.2 MAINTENANCE AND OPERATION

The quality of construction of a gas-cleaning device, the optimum matching of its operating characteristics to the solution of the cleaning task, and the degree of attention given to its proper operation strongly influence the operating and maintenance costs of the equipment. These combined costs can range from as low as 15 percent of the annualized total cost of control for dry centrifugal collectors to as high as 90 percent for a high-efficiency wet collector.

The expenditure that results from operating a control device at its designed collection efficiency for a period of 1 year is the annual operating cost. This expenditure is related to the gas volume cleaned, the pressure decrease across the system, the total time the device is operated, the consumption and costs for electricity and scrubbing liquor,

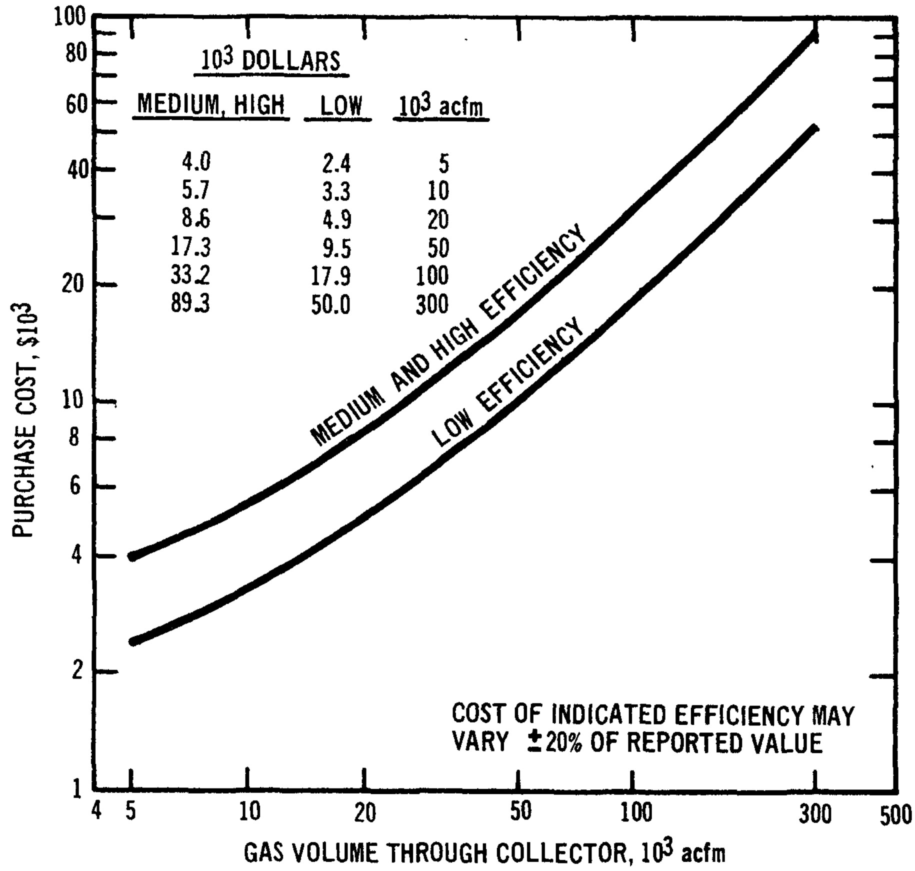


Figure 4-3. Purchase cost of wet collectors (February 1972 estimate).

Table 4-1. AIR POLLUTION CONTROL EQUIPMENT COLLECTION EFFICIENCIES

Equipment type	Typical efficiency ranges (on total weight basis), percent
Low-energy mechanical	50 to 70
High-energy mechanical	70 to 90
Low-energy wet collector	50 to 75
Medium-energy wet collector	75 to 90
High-energy wet collector	90 to 99.5+
Fabric filter[a]	95 to 99.9

[a]Collection efficiency for a properly designed and operated unit should be greater than 99.5 percent.

and the mechanical efficiencies of fans and pumps. Table 4-5 lists theoretical cost equations that incorporate these factors.

The annual maintenance cost is the expenditure incurred in sustaining the operation of a control device at its designed efficiency for a period of 1 year. A scheduled maintenance program accompanied by the

Table 4-2. COST-CAPACITY FACTORS FOR GAS CLEANING DEVICES[2]

Collector type	Cost-capacity factor[a]
Fabric	
Fabric filter, shaker	0.87
Fabric filter, envelope	0.87
Fabric filter, reverse jet	0.78
Mechanical	
Medium-efficiency cyclone	0.87
High-efficiency cyclone	0.82
Multiple cyclone	0.86
Wet	
Wet dynamic scrubber	0.78
Low-energy venturi	0.82
High-energy venturi	0.70

[a]Cost-capacity factor, n, such that $C_2 = C_1\left(\frac{Q_2}{Q_1}\right)^n$. See text.

Table 4-3. INSTALLED COST EXPRESSED AS A PERCENTAGE OF PURCHASE COST FOR TYPES OF CONTROL DEVICES[1]

Generic type	Cost range,[a] percent			
	Low	Typical	High	Extremely high
Dry centrifugal	140	150	200	500
Wet scrubber				
Low, medium energy	150	200	300	500
High energy[b]	200	300	500	600
Fabric filters	150	180	200	500

[a]See Table 4-4 for conditions that determine cost range.

[b]High-energy scrubbers usually require more expensive fans and motors.

prompt replacement of defective and worn parts is recommended practice. Maintenance costs expressed relative to the gas-handling capacities of dry centrifugal collectors, wet collectors, and fabric filters are listed in Table 4-6; the 1968 costs of Edmisten and Bunyard[1] have been adjusted to a February 1972 basis. To simplify the computational procedure, annual maintenance costs averaged over the useful life of the equipment are presented; it is expected in practice that such costs would show an increasing maintenance trend with wear and age of the control devices. The method of including maintenance cost into total annual operating

Table 4-4. CONDITIONS AFFECTING PURCHASE AND INSTALLATION COSTS[1]

Cost category	Low to typical costs	High to extremely high costs
Equipment transportation	Minimum distance; simple loading and unloading procedures	Extensive distance; complex procedure for loading and unloading
Plant age	Hardware designed into new plant as an integral part of process	Hardware installed into confines of old plant requiring structural or process modification or alteration
Available space	Vacant area for location of control system	Little vacant space; extensive steel support construction and site preparation required
Instrumentation	Little required	Complex instrumentation required to assure reliability of control or constant monitoring of gas stream
Guarantee on performance	None required	Guaranteed high collector efficiency to meet stringent control requirements
Degree of engineering design	Standard "package type" control system	Control system requiring extensive integration with process, insulation to correct temperature and moisture problem, noise abatement
Degree of assembly	Control hardware shipped completely assembled	Control hardware to be assembled and erected in the field
Utilities	Electricity, water, waste disposal facilities readily available	Electrical and waste treatment facilities must be expanded; water supply must be developed or expanded
Collected waste material handling	No special treatment facilities or handling required	Special treatment facilities and/or handling required
Labor	Low wages in geographical area	Overtime and/or high-wage geographical area
Auxiliary equipment	Simple draft fan; minimal ductwork	Extensive cooling equipment ductwork, large motors
Corrosiveness	Noncorrosive gas	Acidic emissions requiring high alloy accessory equipment using special handling and construction techniques

Table 4-5. EQUATIONS FOR CALCULATING ANNUAL OPERATION AND MAINTENANCE COSTS[a,1]

Operation costs

Control device	Electrical costs (A)[a]	Liquor consumption costs(B)[a]	Maintenance costs (C)[a]
Centrifugal collector	$S\frac{0.7457\ PHK}{6356\ E}$	–	SM
Wet collector	S (0.7457) HKZ	SWHL	SM
Fabric filter	$S\frac{0.7457\ PHK}{6356\ E}$	–	SM

[a]Note: annual cost (dollars) for operating and maintenance, G = (A) + (B) + (C) where:
- S = Design capacity of the unit in actual cubic feet per minute (acfm).
- P = Pressure drop in inches of water.
- H = hours of operation annually.
- K = cost of electricity in dollars per kilowatt-hour.
- E = fan efficiency expressed as percertage.
- M = maintenance cost per acfm in dollars per acfm.
- W = make-up liquor rate in gallons per hour per acfm.
- L = cost of liquor in dollars per gallon.
- Z = Total power input required for a specified scrubbing efficiency in horsepower per acfm.

Table 4-6. ANNUAL MAINTENANCE COST FACTORS FOR TYPES OF CONTROL DEVICES

Generic type	Cost, $/acfm		
	Low	Typical	High
Dry centrifugal	0.006	0.020	0.032
Wet collector	0.03	0.05	0.08
Fabric filter	0.03	0.06	0.10[a]

[a]Exotic materials can result in higher maintenance.

and maintenance expenditure is indicated in Table 4-5.

Costs for electricity and water, adjusted to February 1972, are shown in Table 4-7. Also, requirements of make-up water and power for wet collectors and the pressure loss typical of the types of control devices are indicated.

4.3 CAPITAL CHARGES

Taxes, insurance, and interest on borrowed capital are included in the category of capital charges. These charges are widely variable, ranging from 6 to 12 percent per year, and depend upon the industry's financial position and ability to borrow money, the existing money market, and the local tax structure. A rate of 7 percent per year of the capital investment, or total installed cost, can be assumed in the absence of detailed data on a particular installation.

4.4 ANNUALIZATION OF COSTS

The annualized capital cost of an air pollution control system is calculated by depreciating the total installed cost, or capital investment, over the useful life of the control equipment and adding the capital charges. The depreciation is commonly based upon a

Table 4-7. COST (FEBRUARY 1972) AND ENGINEERING FACTORS FOR DETERMINING OPERATING COSTS FOR EMISSION CONTROL EQUIPMENT

Control equipment	Cost or engineering parameter	Range		
		Low	Typical	High
All devices	Cost of electricity, \$/kwh[a]	0.006	0.013	0.024
Wet scrubber	Cost of liquor, \$$10^{-3}$/gal[a,b]	0.12	0.31	0.65
Dry centrifugal	Pressure loss through equipment, in. water	–	2 to 3	4
Fabric filter		2 to 3	4 to 5	6 to 8
Wet collector	Fan loss Pump loss	1 1 to 3	10 1 to 5	20 to 60 1 to 10
		Low Efficiency	Medium Efficiency	High Efficiency
Wet collectors	Scrubbing (contact) power, horsepower/acfm[c]	0.0013	0.0035	0.008
	Make-up liquor rate, gal/acfm-hr	0.03	0.03	0.03

[a]Based on national average for large consumers.

[b]Assume H_2O for make-up.

[c]Data do not include requirements for pumping water through system. Such requirements may range from 0.0 to 0.5 horsepower per 1000 acfm.

straight-line computation because this yields a constant annual write-off. Factors such as obsolescence of control equipment and functional lifetime determine the depreciation period, which varies considerably among industries. A depreciation period of 15 years can be assumed typical for most control systems.

The *total annualized cost of air pollution* control is the sum of the annualized capital cost, the annual operating cost, and the annual maintenance cost.

4.5 EXAMPLES

Example 1

An asbestos-cement pipe manufacturing plant controls emissions by the use of a baghouse with medium-temperature-type filters and a capacity of 124,000 acfm. The total installed cost of the system, adjusted to a 1972 cost basis, is \$295,000; the annual cost of above-average maintenance is \$14,000. Complex ducting was required for the installation.

To compare the above actual costs with those predicted by the estimation method of this chapter, the purchase cost is read from curve B of Figure 4-1 as \$65,000. The inclusion of complex duct work places the cost range of the control system within the range of "high" to "extreme high" of Table 4-3 as indicated by reference to Table 4-4. Accordingly, the total installed cost is estimated to be between 2 x \$65,000 = \$130,000 and 5 x \$65,000 = \$325,000; the actual total installed cost is included in this range. The use of the high maintenance cost factor, \$0.10/acfm, yields an annual maintenance cost of \$12,400, which is in reasonable agreement with the actual value of \$14,000.

Example 2

Emissions from brake-lining machining operations are controlled by the use of an 18,000-acfm reverse-air-cleaned baghouse with medium-temperature-type polypropylene felt tubes. The total installed cost of the system is \$24,900. Minimal hooding and ductwork were required for the installation.

By the estimation method of this chapter, the purchase cost is read from curve B of Figure 4-1 as \$14,000. Because only minimal ductwork was required, the installed cost of the control system is within the range of "low" to "typical" of Table 4-3, as indicated by reference to Table 4-4. Accordingly, the total installed cost is estimated to be between 1.5 x \$14,000 = \$21,000 and 1.8 x \$14,000 = \$25,200; the actual total installed cost of \$24,900 is included in this range.

Example 3

A vinyl-asbestos tile manufacturing plant uses a 4,500-acfm continuously cleaned baghouse with medium-temperature-type woven-cotton bags to control emissions from an asbestos bag-opening operation. The total installed cost is \$11,900, and the annual cost of average maintenance is \$310. No complex ductwork was required for the installation.

To compare the above actual costs with those predicted by the estimation method of this chapter, the purchase cost is read from curve B of Figure 4-1 as \$6,800. Because no complex ductwork was required, the installed cost of the system is included in the range of "low" to "typical" of Table 4-3, as indicated by Table 4-4. Accordingly, the total installed cost is estimated to be between 1.5 x \$6,800 = \$10,200 and 1.8 x \$6,800 = \$12,240; the actual value is included in this range. The use of an average maintenance cost factor from Table 4-6 yields an annual maintenance cost of \$0.06/acfm x 4,500 acfm = \$270, which is somewhat less than the actual value of \$310.

Example 4

Emissions from an asbestos ore dryer are to be controlled by a 40,000-acfm baghouse with high-temperature-type felt filters. Costs will be higher than normal because of the requirements of complex field-assembled instrumentation, insulation to combat moisture problems, erection within the confines of an existing plant, and extensive engineering and planning to integrate the control system with the present process design. Detailed analysis by an asbestos-producing company and fabric-filter vendors yielded an estimate of \$225,000 for the total installed cost.

By the estimation process of this chapter, the purchase cost is read from curve A of Figure 4-1 as \$48,000. By virtue of the several complicating conditions listed above, the cost of the installed control system is estimated to be within the range of "high" to "extreme high" of Table 4-3, as indicated by reference to Table 4-4. Accordingly, the total installed cost is estimated to be between 2 x \$48,000 = \$96,000 and 5 x \$48,000 = \$240,000. The estimate, by detailed analysis, of \$225,000 is included in this range and is closer to the higher value as would be indicated by the existence of several complicating conditions.

4.6 REFERENCES FOR SECTION 4

1. Edmisten, N. G. and F. L. Bunyard. A Systematic Procedure for Determining the Cost of Controlling Particulate Emissions from Industrial Sources. J. Air Pollution Control Assoc. *20(7)*:446-452. July 1970.
2. Zimmerman, O. T. and I. Lavine. Cost-Capacity Factors – Equipment. Cost Engng. *6(2)*:13-18. April 1961.

5. EVALUATION OF ASBESTOS EMISSIONS

The evaluation of community air pollution frequently requires that the quantities and characteristics of pollutant emissions from a large number of sources of diverse types be determined. As an alternative to the individual testing of each emission source, a procedure for estimating typical or averaged emissions from various source types by the application of emission factors has been adopted.

An emission factor for a given technological process is an average (for a number of individual processes of the specified source type) of the amount of an emitted pollutant divided by some appropriate measure of the productivity, material input, or energy transfer that is associated with the process. Consequently, knowledge of the emission factor for a given source type and pollutant together with the corresponding productivity, material input, or energy transfer parameter for the individual plant or facility permits the rate of pollutant emission to be calculated. Emission factors are preferably derived from extensive and detailed source sampling data that can be directly related to process variables. Significant differences regarding the type of process and the degree of air pollution control among individual sources within a category should be specified.

No accurate asbestos emission factors are available. Mass-rate emission factors, based on engineering appraisals and extremely limited data, have been compiled and published;[1] but emission factors, based on asbestos fiber counts, have not been compiled. Since health effects of asbestos are related to the number magnitude of fiber exposure, extensive data should be collected in order to determine accurate estimates of fiber count-rate emission factors for asbestos.

5.1 REFERENCE FOR SECTION 5

1. National Inventory of Sources and Emissions, Asbestos, Section III. Leawood, W. E. Davis and Associates, NAPCA Contract Number CPA 22-69-131, 46 p., February 1970.

6. DEVELOPMENT OF NEW TECHNOLOGY

Research is in progress to find substitute materials for the asbestos contained in spray fireproofing for steel and reinforced concrete structures and for the asbestos in pipe insulating materials. This research has already produced some asbestos-free spray fireproofing materials, which have been marketed. In another application, amosite has been replaced by fiber glass in boiler blankets for naval vessels. On the other hand, interest in expanding the already vast number of applications for asbestos fibers has increased.

There are available gas-cleaning devices of the fabric-filter type, which can reduce fiber counts to below levels presently required by industrial hygiene standards. Should fibers of submicron diameter be discovered to contribute significantly to adverse health effects, however, it would be necessary to determine fractional collection efficiencies of fabric filters for this range of fiber sizes. Fractional collection efficiency data, required for a more complete evaluation of the effectiveness of fabric filters as control devices, are apparently not available at present. As an initial measure, standardized laboratory tests for the total mass collection efficiency of filter fabrics should be developed.

The treatment of surfaces of mill tailings dumps to promote the growth of vegetation, thereby securing the material from atmospheric entrainment and dispersion, is presently under investigation. Only limited success has been achieved. Also, methods to revegetate and to reforest exposed mining lands are undergoing study and development.

In the manufacture and field fabrication of products containing asbestos, emphasis in abatement activities centers on either the containment or the airborne entrainment and subsequent collection of potential emissions at the sources. New applications of dust-capturing hoods of both the low-velocity, high-volume and high-velocity, low-volume types are expected. Also anticipated are further development and more extensive use of dust elimination methods, such as pulpable bags for utilization in the manufacture of asbestos paper and wet-mix shipping bags for asbestos-fiber products.

APPENDIX A. GAS CLEANING DEVICES

Brief descriptions of three gas-cleaning devices (fabric filters, dry centrifugal collectors, and wet collectors), which can be applied to control emissions of asbestos, are presented. For a more complete discussion of these control devices, the reader is referred to Reference 1 of this section.

A.1 FABRIC FILTERS

Fabric filters, which have been in commercial use for many years, provide one of the most reliable methods for cleaning solid particulate material from gas streams. Particulates as small as 0.5 μm in diameter can be collected with high efficiency, and even those as small as 0.1 μm can be removed at somewhat reduced efficiency after a dust layer has been deposited on the fabric.[1]

In this type of filter, a gas stream passes through the woven or felted fabric filtering medium and deposits dust on the upstream, or dirty gas, side of the material. The most common geometrical configuration of the fabric filter, illustrated in Figure A-1, is a group of vertical tubes forming a baghouse: flat areas of fabric material as well as curved surfaces are employed. Dust is dislodged from the surface of the filter either by flexing the fabric or by locally directing a stream of air through the filter in the reverse direction.

The nature of the collecting mechanism of a fabric filter is quite complex, as might be judged from the fact that solid particles of much smaller diameter than the equivalent open spaces in clean filtering material are frequently collected with high efficiencies.[1] Initially, particles are deposited and retained on the fibers of a fabric by direct interception, initial impaction, diffusion, electrostatic attraction, or gravitational settling. After a cake or mat of dust has accumulated on the filter material, the collection efficiency is increased significantly by the effect of mat sieving. Most of the dust mat is removed during each filter cleaning.

A measure of the flow resistance of clean, new filtering material is the ASTM (American Society for Testing and Materials) permeability. This parameter is defined as the volumetric rate of air flow in cubic feet per minute (cfm) through 1 square foot of fabric that produces a pressure decrease of 0.5-inch water gauge across the fabric. The permeability is also related to the initial penetration of dust through a clean fabric. An important operating parameter of a fabric filtering installation is the air-to-cloth ratio, or filtering velocity; this factor is defined as the total volumetric flow rate through the filter, expressed in cubic feet per minute divided by the total number of square feet of filtering area.[1]

Fabric filters are used extensively in the asbestos mining, milling, and manufacturing industries. Table A-1 shows typical characteristics of the fabric filters chosen by a large corporation for asbestos collection from a wide range of emission-source types. The filter material is cotton sateen except in the case of control of emissions from an ore dryer; cotton is unsuitable for the higher-temperature effluent gases of the dryer. The useful lifetime of cotton bags is 6 to 7 years.[2] Wool felts have also been used for several years, but synthetic felts have only recently gained acceptance by the asbestos industry. A wide range of synthetic felted fabrics is now available; these fabrics can be designed for specific particle size ranges and particulate loadings to achieve collection

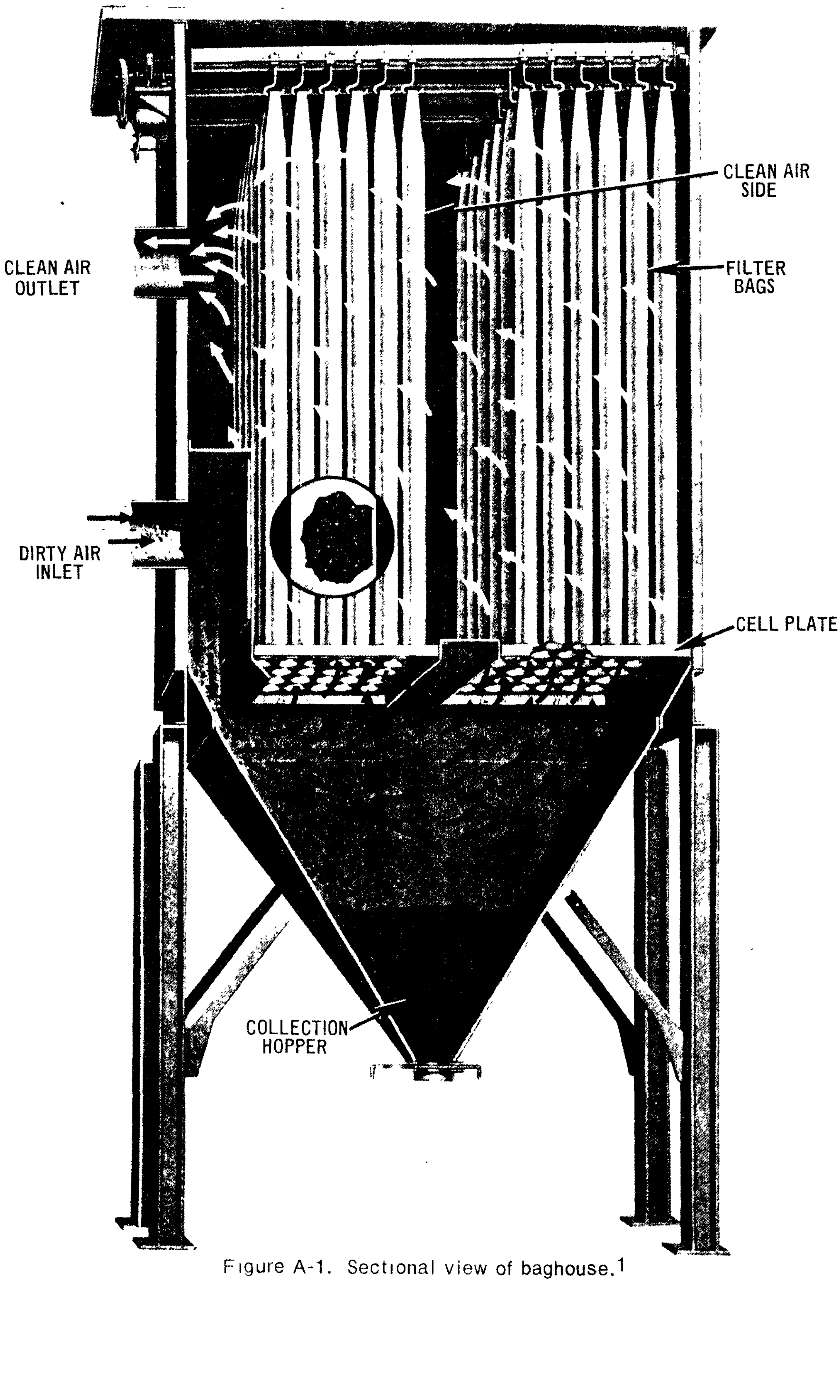


Figure A-1. Sectional view of baghouse.[1]

Table A-1. APPLICATIONS OF FABRIC FILTERS[a,1]

Application	Operation	Cloth	Bag length, in.	Bag diameter, in.	Filtering velocity, ft/min	Expected pressure drop, in. H_2O
Asbestos milling	Continuous	Cotton sateen	168	5	2.5 to 3.0	2.5 to 4.0
Asbestos ore dryers	Continuous	Orlon	168	5	2.5	1.5 to 2.0
Asbestos-cement raw material handling	Continuous	Cotton sateen	126	5	2.5	3.0
Asbestos-cement finishing machines	Intermittent	Cotton sateen	168	5	2.0	1.5 to 2.0
Textile carding	Intermittent	Cotton sateen	126 to 168	8	5	1.5 to 2.0

[a]Data based on several plants of one corporation.

efficiencies equivalent to less permeable cotton fabrics.

The nature of some of the processes described in Table A-1 requires that the collectors operate continuously; whereas, in other instances the filters can be cleaned periodically when a process is shut down. Cleaning cycles vary from 1 minute of shaking during each 30 minutes of operation in a mill to one cleaning every 2 hours of operation at the finishing end of an asbestos-cement pipe manufacturing plant.[2] Woven bags are usually cleaned by the action of a mechanical shaking device. Baghouses equipped with felted fabrics usually operate continuously and employ pulse-jet cleaning in which a jet of compressed air is periodically released through a venturi at the top of each bag. The rapid flexure of the fabric and subsequent rebound against an internal restraining screen effect cleaning. Differences in bag length and diameter among the collectors result from space and efficiency compromises among small-diameter bags to minimize required floor area, larger-diameter bags to reduce the likelihood of longer fibers plugging the filters, and longer bags to fit a filter into smaller floor area.

In an asbestos mill, collection efficiencies greater than 99.99 percent have been exhibited by fabric filters receiving an inlet dust concentration of approximately 1 gram per standard cubic foot.[2] The consistent attainment of an exit fiber concentration of 0.5 fiber per cubic centimeter (measured by membrane filter technique) from a well-maintained baghouse is thought possible with cotton sateen fabric under the operating conditions used in Table A-1. Tests have shown that exit dust concentrations observed immediately after initiating air flow through a cleaned cotton sateen bag are considerably larger than those for normal operation; the much lower values are reached only after a time interval of 2 or 3 minutes. Woven fabrics of synthetic material presently exhibit larger relative exit dust concentrations initially and require longer periods of time to reach normal levels.[2] A regular maintenance program is essential for the realization of maximum efficiency of fabric filters; the presence of dust on the clean air side is almost always the result of leaks or breaks in the bags.[2]

As shown in Table A-1, filtering velocities range from 2.0 to 5.0 feet per minute for woven fabrics. Typical permeabilities are approximately 20 and 30 cubic feet per minute per square foot for cotton sateen and felted fabrics, respectively.

The proper operation of fabric filters requires that moisture not be condensed from the gas stream. Consequently, if a filter enclosure is exposed to low temperature or if a hot, moist gas stream is handled, insulation of the baghouse may be required, as in the case of baghouses applied to asbestos ore dryers.

A.2 DRY CENTRIFUGAL COLLECTORS

Dry centrifugal collectors impart a spinning motion to a dirty gas stream. Many of the relatively dense particulates are not capable of following this motion of the fluid; they impinge on the collector wall, drop to the base of the collector, and are removed from the device. The required rotary motion, which can be imparted by various methods, is frequently induced by a tangential inlet to the collector vessel. Collector efficiency is determined by the interrelationships among gravitational, radial or centrifugal, and fluid drag forces exerted on the particles of the gas stream.

Conventional reverse-flow cyclones with tangential gas inlet and axial inlet are illustrated in Figures A-2 and A-3, respectively. Dry centrifugal collectors are commonly employed in the asbestos milling and manufacturing industries, both as precleaners for fabric filters and as process equipment for the separation of longer asbestos fibers from shorter fibers and wastes.

Cyclone collection efficiency can be specified in terms of the cut size, which is defined as that particle diameter which is collected with a 50 percent efficiency on a weight basis.[1] Large-diameter conventional cyclones have a high collection efficiency for particles with diameters as small as 40 to 50 micrometers.[1] The pressure decrease across dry centrifugal collectors is in the range of 1 to 8 inches of water.[1]

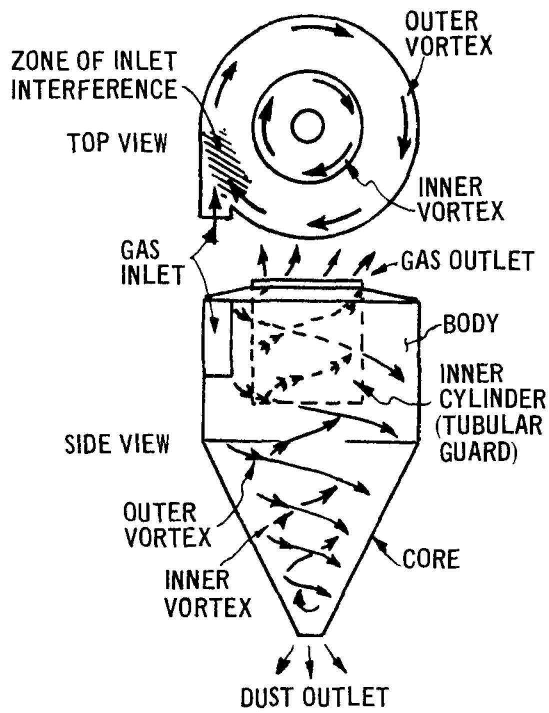


Figure A-2. Reverse-flow cyclone with tangential inlet.[1]

A.3 WET COLLECTORS

Water and other liquids are employed in wet collectors to entrap and remove particulates from gas streams. This action is accomplished by bringing droplets of scrubbing liquid into contact with the undesired entrained particles to render the particle sizes large enough to permit high-efficiency collection. The mixture of collected material and scrubbing liquor is readily removed from the cleaning device to minimize reentrainment of the original contaminating material. Spray chambers, centrifugal spray scrubbers, impingement plate scrubbers, venturi scrubbers, packed-bed scrubbers, and centrifugal-fan wet scrubbers are among the many types of wet collectors in commercial use. In the venturi wet collector (Figure A-4), scrubbing liquid is introduced into the dirty gas stream at the throat of the venturi, the location of highest gas velocity. Collection efficiency is enhanced with the increase of the velocity of the entrained particulates relative to the droplets of

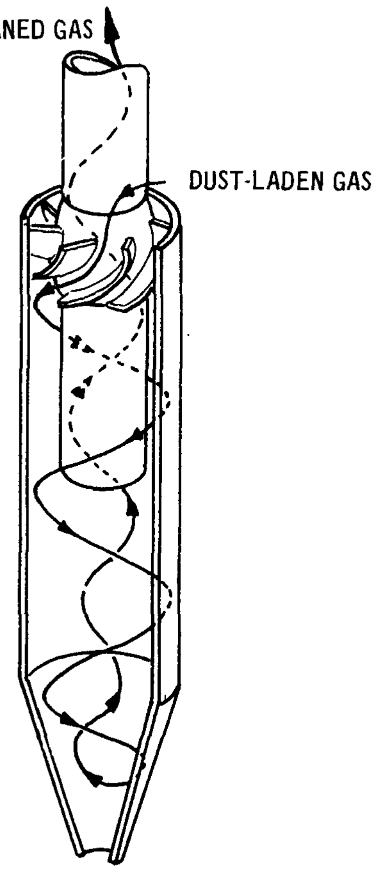


Figure A-3. Reverse-flow cyclone with axial inlet.[1]

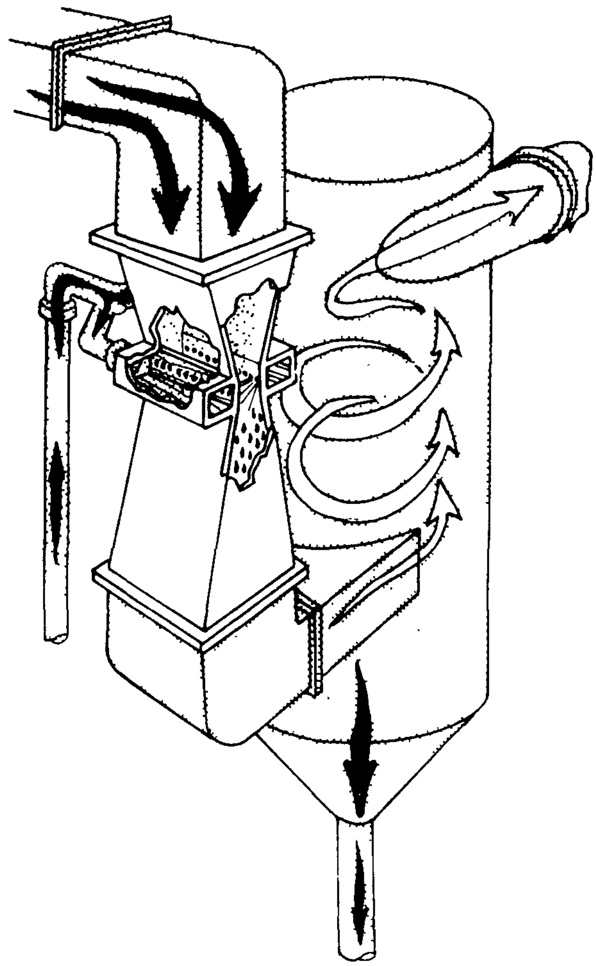


Figure A-4. Venturi wet collector.[1]

scrubbing liquid produced by the impingement of the gas flow against the injected liquid. In the case of the centrifugal-fan wet scrubber (Figure A-5), the particulates of the dirty gas stream and droplets of scrubbing liquor are dynamically precipitated by the action of the centrifugal blower.

A primary disadvantage of using wet collectors as final-stage gas-cleaning devices for the control of asbestos emissions is the apparent low collection efficiency for submicron particulates. Some wet collectors, for example those of the venturi type, can be designed for improved efficiency in the collection of submicron particle sizes, but the operating costs become excessive for the resultant higher values of pressure drop across the scrubbers.

A.4 REFERENCES

1. Control Techniques for Particulate Air Pollutants. U. S. Department of Health, Education, and Welfare, National Air Pollution Control Administration. Publication Number AP-51. January 1969. p. 44-81, 102-126.
2. Goldfield, J. Fabric Filters in Asbestos Mining and Asbestos Manufacturing. (Presented at the APCO Fabric Filter Symposium, Charleston, March 1971.) p. 10, 15, 17-19.

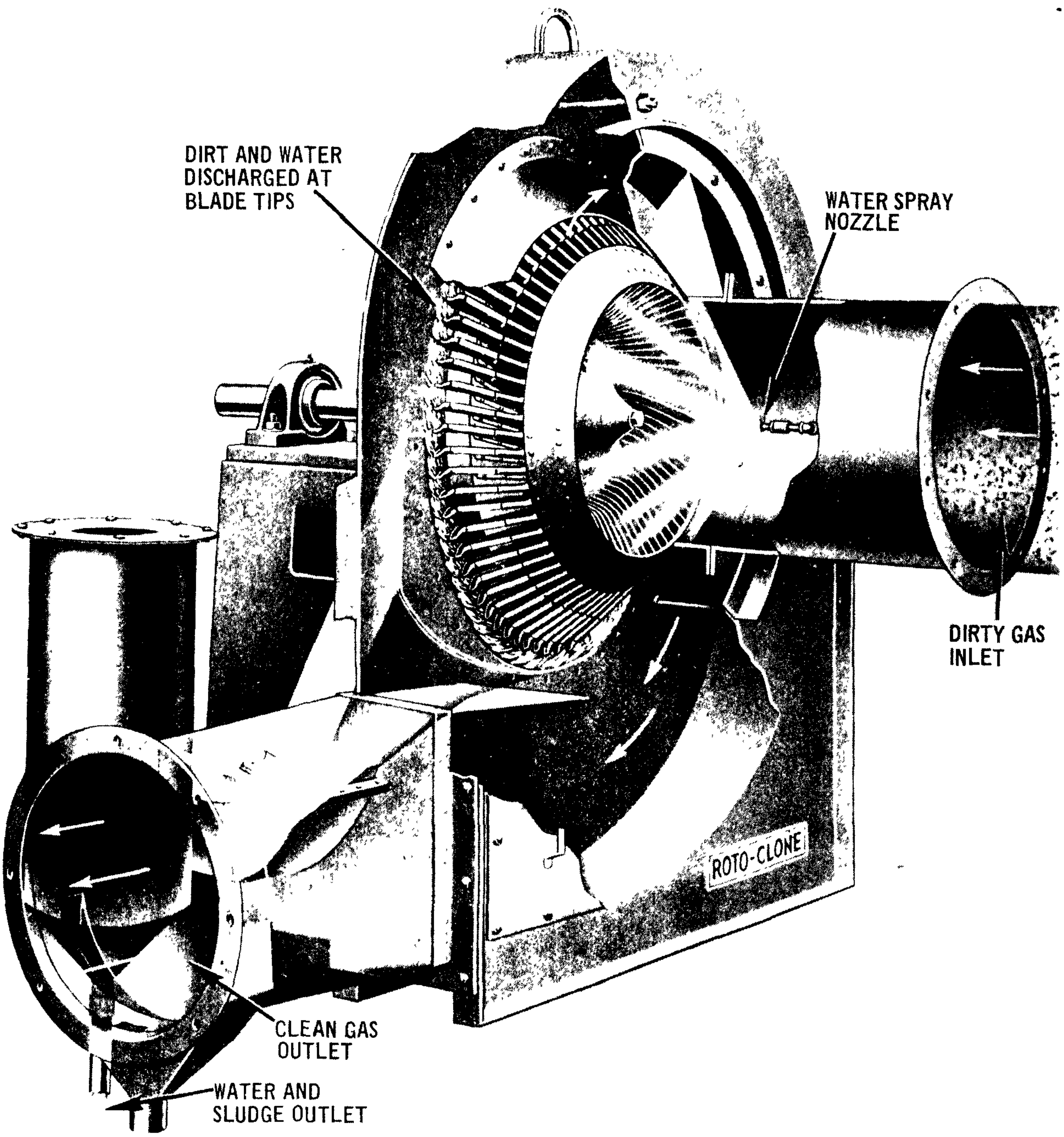


Figure A-5. Centrifugal fan wet scrubber.[1]

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