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Control of Volatile Organic Emissions from Manufacture of Pneumatic Rubber Tires

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Control of Volatile Organic Emissions from Manufacture of Pneumatic Rubber Tires

Emission Standards and Engineering Division
Chemical and Petroleum Branch

U.S. ENVIRONMENTAL PROTECTION AGENCY
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OAQPS GUIDELINE SERIES

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ABBREVIATIONS AND CONVERSION FACTORS

EPA policy is to express all measurements in agency documents in metric units. Listed below are abbreviations and conversion factors for British equivalents of metric units for the use of engineers and scientists accustomed to using the British system.

Abbreviations

Mg - Megagrams

kg - kilograms

m^3 - cubic meters

Conversion Factors

liters X .264 = gallons

gallon X 3.785 = liters

gram X 1 X 10^6 = 1 Megagram = 1 metric ton

1 pound = 0.454 kilograms

^oC = .5555 (^oF - 32)

Mg/yr X 0.907 = tons/yr

1 psi = 6,895 pascals (Pa)

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1.0 INTRODUCTION

This document is concerned with emissions of volatile organic compounds (VOC) from rubber tire manufacturing plants and applicable air pollution control technology. Tire manufacture includes passenger car, light and medium duty truck tires, and tires manufactured on assembly lines using automated equipment and processes fundamentally the same as those described in this document.

Methodology described in this document represents the presumptive norm or reasonably available control technology (RACT) that can be applied to existing tire manufacturing plants. RACT is defined as the lowest emission limit that a particular source is capable of meeting by the application of control technology that is reasonably available considering technological and economic feasibility. It may require technology that has been applied to similar, but not necessarily identical, source categories. It is not intended that extensive research and development be conducted before a given control technology can be applied to the source. This does not, however, preclude requiring a short-term evaluation program to permit the application of a given technology to a particular source. The latter effort is an appropriate technology forcing aspect of RACT.

The VOC's emitted are predominately white gasoline and pertroleum naphtha solvent used in rubber tire manufacturing. Toluene, xylene, ketones, and esters are used for many purposes, but generally in lesser amounts. Other hydrocarbons of importance include plasticizers and softeners that have low volatility at ambient temperatures but evaporate during curing and other high temperature processing steps.

1.1 NEED TO REGULATE

Tire manufacturing tends to be concentrated in areas where the oxidant National Ambient Air Quality Standard (NAAQS) is likely to be exceeded. In 1976, VOC emissions resulting from production activities carried out by the rubber industry were estimated to be 1.4 x 10^8 kilograms. The tire industry represented 63 percent of that total or about 0.6 percent of the national organic emissions from stationary sources. The average tire plant is estimated to release 4,000 kg per day emissions or 1,000 metric tons per year VOC.

1.2 REGULATORY APPROACH

VOC emission reductions from tire manufacturing can be attained through tight control of solvent operations and the use of effective capture systems and exhaust gas treatment devices. Sources and the factors affecting emissions are described in Chapter 2. Control systems for specific processes are described in Chapter 3. Costs are presented in Chapter 4.

1.3 SUMMARY

The purpose of this document is to inform State and local air pollution control agencies of techniques available for reducing emissions of volatile organic compounds (VOC) from rubber tire manufacturing. Volatile organic compounds are added to rubber components to aid in mixing, promote elasticity, produce tack (stickiness), or extend (replace) a portion of the rubber hydrocarbons. Tire production includes the operations of component manufacture, assembly, and cure. Essentially all solvents used in tire manufacturing evaporate in the process.

Recommendations to reduce solvent emissions from tire manufacture are based upon exhaust gas treatment and process changes (principally lowering the solvent content of raw materials).

Tires are manufactured in a series of operations and processes using large quantities of solvents. These result in the emission of large quantities of vapors and mists into work room air. To meet OSHA workplace standards, increased ventilation and dilution air is generally used. Well designed hooding and ventilation systems are necessary both to meet OSHA requirements and to facilitate the application of air pollution control equipment. Two manuals are suggested as references on the design and operation of industrial ventilation systems.[1,2]

It is estimated that 97 percent of VOC emissions from tire manufacturing are organic solvents; the rest are reaction products generated during curing. Green tire spraying, undertread cementing, tread end cementing, and bead dipping represent 75-85 percent of emissions and tire building 12-20 percent. Green tire spraying and undertread cementing are the dominant VOC emitters as shown in Table 1-1. Control of tire building is not presently recommended because of the very large areas over which these emissions occur (i.e., 50 tire building machines per average plant, occupying about 25 percent of the plant floor space). Retrofit control would have to be applied to very large air volumes with low VOC concentrations.

Other emission points not considered in this document are latex dipping, compounding, calendering, extrusion, milling, and curing. Latex dipping is moving from tire plants to the textile mill operations. Research and development has been initiated by EPA with industry participation to determine hood design criteria, emission levels, and feasibility of control technologies, of emissions from the passenger tire curing process. It is estimated that the emissions from these six sources represent 3-6 percent of tire plants total emissions.

The following table summarizes the four major sources of VOC emissions from tire manufacturing and the control technology for each that is considered reasonably available.

TABLE 1-1

Control Systems for Tire Manufacture (typical 16,000 tires daily production rate)[1]

Affected Facility	Control Technology	Uncontrolled Emissions kg/day	Capture Efficiency[2] percent	Efficiency Across Control Device percent	Overall Efficiency percent
Undertread Cementing	Carbon Adsorption or	1520	65-85	95	62-81
	Incineration		65-85	90	59-77
Tread-End Cementing	Carbon Adsorption or	240	65-85	95	62-81
	Incineration		65-85	90	59-77
Bead Dipping	Carbon Adsorption or	130	75-85	95	71-81
	Incineration		75-85	90	68-77
Green Tire Spraying	Water Based Coating	1600	NA	NA	97[3]
	Carbon Adsorption or	1600	80-90	95	76-86
	Incineration		80-90	90	72-81

[1] Based on an average tire weight of 11.4 kg.

[2] Percent capture efficiency for a retrofit will vary depending on the design and layout of the individual affected facility; minimum acceptable percent capture should be determined on an individual plant basis.

[3] This number depends upon the formulation.

Water based coatings are available to replace organic solvent based coatings commonly used in green tire spraying. Use of water based coatings will reduce VOC emissions by nearly 100 percent. These are already in use at tire plants.

The other three principal VOC sources can be controlled by applying stack gas treatment--adsorption or incineration--together with an effective capture system. In many existing facilities, the layout and method of operation for undertread cementing, bead dipping, and tread end cementing systems make it difficult to achieve a high capture efficiency. For the latter two sources in particular, this means that VOC levels may often be low (less than 75 ppm) with resultant air pollution control costs ranging from 1140 to 3880 $/Mg of VOC controlled. Undertread cementing operations can usually be hooded more effectively, such that VOC levels will be more concentrated and control costs more reasonable, i.e., from 166 to 505 $/Mg. Application of adsorption or incineration to those installations where effective capture systems can not be installed could have severe economic impact and require substantial energy penalties.

2.0 SOURCES AND TYPES OF EMISSIONS

The purpose of this chapter is to describe the current industry, provide a brief process description, indicate emission points and identify the VOC species that are emitted.

Pneumatic tires are constructed from strong fibers (rayon, nylon, polyester, glass or steel) impregnated with polymers (synthetic and natural rubber) and overlayed with a tread of wear-resistant polymer such as styrene-butadiene rubber (SBR). These are built up individually by a skilled tire builder, and cured into the familiar toroidal shape under pressure in a heated mold. Many kinds of tires are made. These include truck, trailer, tractor, construction equipment, bicycle, plane, and passenger car. The passenger car tire is the most produced tire representing about 70 percent of the tires produced in the U. S.

Table 2-1 provides a listing of the United States tire company's production facilities, and estimated 1977 tire production.[1,2] Since 1975, four plants have been closed.[3,4,5] Construction of three new plants, one by Goodyear and two by Michelin, has been announced.[6] Firestone also plans to double the production capacity of its heavy-duty radial truck tire plant in Nashville, Tennessee, by 1982.[7]

Table 2-2 shows the number of passenger car and truck tires produced for the original equipment and the replacement tire markets for the years 1974 through 1977.[8,9,10,11] During the period 1974 through 1977, total production of truck tires has shown a growth rate of approximately six percent per year; however, the growth rate for passenger car tires during the same period was less than three percent per year.

TABLE 2-1. ESTIMATED TIRE PRODUCTION BY PLANT AS OF JANUARY 1, 1978[1-4,a]

Company	Plant location	Tires produced, thousands/day: Passenger tires	All others	Total tires
Armstrong Rubber Co.	Des Moines, IA	11.0	3.5	14.5
	Hanford, CA	11.0	-	11.0
	Natchez, MS	8.0	5.5	13.5
	West Haven, CT	12.0	-	12.0
	Nashville, TN	8.5	9.0	17.5
	Clinton, TN			
		50.5	18.0	68.5
Carlisle Tire and Rubber Co.	Carlisle, PA	-	16.0	16.0
Cooper Tire and Rubber Co.	Findlay, OH	8.4	5.0	13.4
	Texarkana, AR	16.6	2.0	18.6
		25.0	7.0	32.0
Denman Rubber Mfg. Co.	Warren, OH	1.5	2.0	3.5
Dunlop Tire and Rubber Co.	Buffalo, NY	11.1	5.1	16.2
	Huntsville, AL	14.0	-	14.0
		25.1	5.1	30.2
Firestone Tire and Rubber Co.	Akron, OH	16.0	4.5	20.5
	Albany, GA	24.0	1.0	25.0
	Bloomington, IL	-	0.1	0.1
	Decatur, IL	21.5	2.9	24.4
	Des Moines, IA	16.0	3.5	19.5
	Los Angeles, CA	8.3	2.0	10.3
	Memphis, TN	15.5	7.0	22.5
	Nashville, TN	-	1.5	1.5
	Pottstown, PA	21.5	2.0	23.5
	Salinas, CA	12.5	2.4	14.9
	Wilson, NC	15.0	-	15.0
		150.3	26.9	177.2
Firestone Subsidiaries				
Dayton Tire and Rubber Co.	Dayton, OH	10.0	7.0	17.0
	Oklahoma City, OK	20.0	2.0	22.0
Seiberling Tire and Rubber Co.	Barberton, OH	8.0	2.5	10.5
		38.0	11.5	49.5
General Tire and Rubber Co.	Akron, OH	-	8.5	8.5
	Bryan, OH	-	0.1	0.1
	Charlotte, NC	17.0	-	17.0
	Mayfield, KY	25.0	9.0	34.0
	Waco, TX	15.7	5.3	21.0
	Mt. Vernon, IL	9.9	0.1	10.0
		67.6	23.0	90.6
B. F. Goodrich Co.	Akron, OH	-	0.5	0.5
	Ft. Wayne, IN	18.4	6.1	24.5
	Miami, OK	5.6	7.0	12.6
	Oaks, PA	18.0	1.0	19.0
	Tuscaloosa, AL	30.0	-	30.0
		72.0	14.6	86.6

(continued)

[a]Dashes indicate plant does not produce type of tire listed; blanks indicate information not available.

TABLE 2-1. (continued)

Company	Plant location	Tires produced, thousands/day		
		Passenger tires	All others	Total tires
Goodyear Tire and Rubber Company	Akron, OH	10.0	11.0	21.0
	Danville, VA	-	7.0	7.0
	Gadsden, AL	26.5	13.5	40.0
	Jackson, MI	21.0	3.5	24.5
	Los Angeles, CA	-	5.0	5.0
	Topeka, KS	23.0	5.5	28.5
	Union City, TN	38.0	-	38.0
	Madisonville, KY			
		118.5	45.5	164.0
Goodyear Subsidiaries				
Kelly-Springfield Tire Company	Cumberland, MD	10.5	8.5	19.0
	Fayetteville, NC	34.0	0.5	34.5
	Freeport, IL	14.5	5.0	19.5
	Tyler, TX	25.0	-	25.0
Lee Tire and Rubber Company	Conshohocken, PA	13.0	-	13.0
		97.0	14.0	111.0
I.P.I	Louisville, KY	0.6	-	0.6
Mansfield Tire and Rubber Co.	Tupelo, MS (plant cosed temporarily, has now reopened)			
McCreary Tire and Rubber Co.	Indiana, PA	2.5	2.5	5.0
Michelin Tire Corp.	Greenville, SC	20.0	-	20.0
Mohawk Rubber Co.	Akron, OH	-	2.1	2.1
	West Helana, AR	9.5	0.5	10.0
	Salem, VA	13.0	0.5	13.5
		22.5	3.1	25.6
Uniroyal, Inc.	Chicopee Falls, MA	22.5	4.0	26.5
	Detroit, MI	14.0	2.0	16.0
	Eau Clair, WI	17.5	7.0	24.5
	Opelika, AL	14.0	3.0	17.0
	Ardmore, OK	32.0	-	32.0
		100.0	16.0	116.0
TOTAL		791.1	205.2	995.3

[a]Dashes indicate plant does not produce type of tire listed; blanks indicate information not available.

TABLE 2-2. ANNUAL DOMESTIC PRODUCTION OF PASSENGER CAR AND TRUCK TIRES FOR ORIGINAL EQUIPMENT AND REPLACEMENT MARKETS[1,5,7,8]

Year	Passenger Car: Original equipment	Passenger Car: Replacement	Passenger Car: Total	Truck: Original equipment	Truck: Replacement	Truck: Total
	Number of tires, millions					
1974	44	127	171	9.6	21.3	30.9
1975	40	123	163	8.3	20.0	28.3
1976	50	125	175	9.2	20.6	29.8
1977	58	126.5	184.5	11.2	25.2	36.4

TABLE 2-3. ANNUAL CONSUMPTION OF RAW MATERIAL FOR USE IN TIRE CORDS AND BELTS[9-11]

Year	Synthetic fabrics: Nylon	Synthetic fabrics: Polyester	Synthetic fabrics: Rayon	Glass fiber	Steel
	Consumption, 10^6 kg				
1973	128	112	42	15	27
1974	130	103	33	12	44
1975	107	86	15	12	54
1976	100	99	12		

A significant trend in raw material consumption is developing within the tire manufacturing industry. As noted in Table 2-3,[12,13] the use of woven synthetic fabrics (nylon, polyester, rayon) for tire cords and belts is gradually declining and giving way to steel. This is primarily due to the growing popularity of radial passenger car tires, 84 percent of which contained steel belts in 1977.[14]

2.1 PROCESSES AND EMISSIONS

The general process for tire manufacturing consists of: (1) preparation or compounding of raw materials, (2) transformation of these compound materials into tire components, (3) tire assembly, and (4) molding of the final product. Each step is a source of VOC emissions.

The average annual mass of VOC emissions, from Table 2-4, for tire manufacturing was estimated to be between 56,300 and 72,500 metric tons per year. Table A-1 lists total annual VOC emissions for each of 42 tire plants. Calculations and assumptions are presented in A-2.

Table 2-4 presents a summary range of operating parameters for existing tire manufacturing plants for undertread cementing, tread end cementing, bead dipping, tire building and green tire spraying.

Table 2-5 presents a summary of the same parameters for an average 16,000 tire per day manufacturing plant.

The following detailed descriptions may be more easily followed by referring to the flow diagram presented in Figure 2-1.

2.1.1 Rubber Stock Processing

2.1.1.1 Compounding - In the compounding operation, raw crumb rubber is combined with a variety of fillers, extenders, accelerators, antioxidants and pigments using Banbury internal mixing devices. Carbon black and oil are also added during

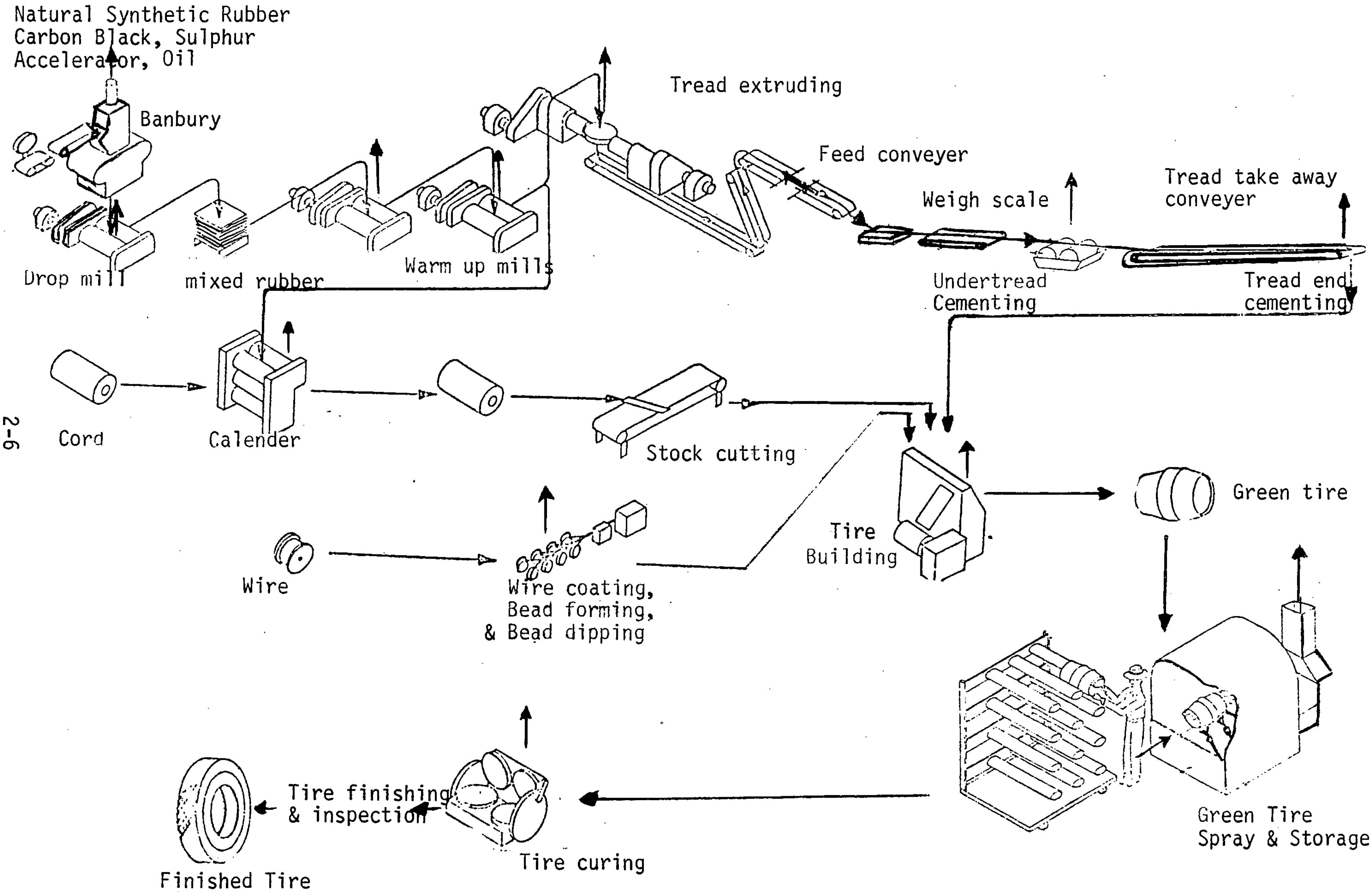

Figure 2-1. Tire Manufacturing Flow Diagram

TABLE 2-4.

RANGES OF OPERATING PARAMETERS FOR EXISTING TIRE MANUFACTURING PLANTS *

Emission Point	Number of Processing Units	Production rate, tires/day/unit	VOC Emission Rate, kg/day/unit	Exhaust Gas flow rate, $m^3/s/unit$	VOC Concentration of exhaust gas, g/m^3	Exhaust Gas Temperature, °C
Undertread Cementing	1 - 13	880 - 24,400	62 - 1,930	0.6 - 4.4	0.72 - 5.0	20 - 30
Tread End Cementing	1 - 7	1,170 - 16,000	5 - 420	0.8 - 9.4	0.02 - 5.2	20 - 25
Bead Dipping	1 - 4	4,830 - 28,500	5 - 420	0.1 - 4.7	0.21 - 3.7	--[a]
Tire Building	33 - 67	180 - 630	6 - 20[b]	3.3 - 10.6	0.01 - 0.32	20 - 25
Green Tire Spraying	1 - 13	100 - 24,400	44 - 1,330	0.6 - 29.3	0.34 - 4.7	20 - 40

* Plant size 100-40,000 tires/day, the low or high range value may not necessarily correspond to product/day.

[a] Range not available.

[b] Estimate

TABLE 2-5. OPERATING PARAMETERS FOR AN AVERAGE TIRE MANUFACTURING PLANT

(Plant size = 16,000 tires/day)

Emission Point	Number of Processing Units	Production rate, tires/day/unit	VOC Emission Rate kg/day/unit	Total kg VOC	Exhaust Gas flow rate, $m^3/s/unit$	VOC Concentration of exhaust gas, g/m^3	Exhaust Gas Temperature, °C
Undertread Cementing	4	4,020	380	1520	2.8	1.57	20
Bead Dipping	2	8,050	65	130	2.7	0.23	20
Tire Building	50	320	10	500	5.7	0.02	20
Tread End Cementing	4	4,020	60	240	3.9	0.18	20
Green Tire Spraying	5	3,220	320	1600	4.6	0.81	20

compounding, and baghouse particulate collectors are normally used to control airborne dust generated by this operation.[15] After mixing, the rubber is transferred to roll mills which form the material into sheets. The tacky sheets of rubber stock are then coated with a material such as soapstone to prevent them from sticking together during storage.

No data on emissions of volatile organic compounds from mixing are available at this time. Using a modified temperature loss correlation proposed by Rappaport[16], and an average tire mass, an emission factor for compounding is estimated to be 1 gram per tire. Calculations are presented in Appendix B.

2.1.1.2 Milling - After compounding, sheeted rubber is fed manually to a warmup roller mill to make the stock more flexible for further processing. From the warmup mill, the heated rubber passes to a strip-feed mill for final mixing. The temperature of the rubber mixture leaving the mill is typically 70°C to 90°C.

Data on milling emissions are also limited. At an operating temperature of only 80°C, 50 percent of the volatile organic compounds emitted during milling are assumed to condense to an aerosol soon after formation. Again, using the modified Rappaport equation, an estimated factor for milling is 0.6 gram per tire.

2.1.1.3 Tread and Sidewall Preparation - the two types of rubber stock to be used for tread and sidewall are peeled from two separate strip mills and continuously fed to an extruder. The two strips are joined together, one on top of the other, by mechanically generated heat and pressure, to form the tire tread and two black sidewalls. After extrusion, a cushioning layer is added to the underside of the tread-sidewall combination which is then cut to the desired width, cooled in a water trough and labeled.

Quantitative information on emissions from extrusion operations in tire manufacturing plants is not available. However, temperatures of 70°C to 90°C, depending on the mass of the extruded product, are reached during extrusion. Assuming that 50 percent of the VOC emissions condense to an aerosol soon after emitted and using the modified Rappaport equation, an emission factor for extrusion is 0.6 gram per tire.

2.1.1.4 Undertread Cementing - Before being transferred to the tire building area, the tread is tackified by the application of a solvent-based cement.

Data on emissions from undertread cementing have been reported by the tire industry.[17,18,19,20,21] Table 2-4 presents summary emission data and operating parameters for existing tire plants. Table 2-5 presents emission data and operating parameters for an average 16,000 tires per day manufacturing plant. Table A-3 presents operating parameters for those plants having capture systems. Solvents typically used for this purpose include heptane, hexane, isopropanol, naphtha, and toluene. The average number of undertread cementing lines per plant is four, each line having an average exit gas flow rate of approximately 2.8 cubic meters per second. Using the methodology described in Appendix A-2, the emission factor for undertread cementing is 94 grams per tire.

2.1.2 Fabric Treatment

2.1.2.1 Latex Dipping - Tire cords and belts are constructed from woven synthetic fabrics such as nylon, polyester, and rayon as well as steel and glass fiber. Upon arrival at a tire manufacturing plant, a roll of fabric is first spliced, either by adhesive or by a high-speed sewing machine, onto the tail of the previously processed roll. This continuous sheet of fabric is then fed under controlled tension to a latex dip tank. After latex dipping, the fabric travels past either rotating beater bars or vacuum suction lines to remove excess dip and then through a drying oven to remove excess solvent.

At the present time, more and more fabric which has undergone latex dipping at the textile mills is being purchased by tire manufacturers. Some of the reasons are:[22] (1) a small dipping operation requires disproportionately large capital expenditures; (2) latex dipping is a high-speed process which can readily over-supply a tire plant with fabric; and (3) on a weight basis, shipping costs for dipped and undipped fabric are nearly the same. Only one tire plant reported to EPA consumption of solvent for on-site latex dipping.[23] Only one other plant is believed to be performing their own latex dipping.

2.1.2.2 Calendering - After the fabric has been latex-dipped, it is passed through a calendering machine which impregnates the fabric with rubber. Both sides of the fabric are coated simultaneously on the four-roll calenders most commonly used. Before being sent to the tire building operation, the rubberized fabric is cooled and cut to the proper angle and length for the tires in which it will be used.

The plasticity of the rubber stock as it is bonded to the fabric, steel mesh, or glass fiber is maintained by heating the calender rolls with steam, typically to temperatures of 70°C to 80°C. Therefore, VOC emissions from calendering should be very similar in character and magnitude to those from milling or extrusion and the estimated emission factor is 0.6 gram per tire.

2.1.2.3 Bead Dipping - Tire beads are rubber-covered wires which insure a seal between a tire and the steel rim of the wheel on which it is mounted.[24] Rubber is simultaneously extruded onto several strands of brass-plated steel wire. Several layers of control wire are fashioned into a ring. A layer of rubber coated fabric is usually wrapped around the bead. The assembly is dipped into a solvent-based cement to tackify the rubber to insure proper adhesion when the bead is anchored into the sidewall when the tire is built.

Table A-4 presents emission and operating data for actual plant bead dipping operations. Table 2-4 presents summary emission data and operating parameters for existing tire plants. Table 2-5 presents emission data and operating parameters for an average 16,000 tire per day manufacturing plant. Solvents consumed for bead dipping activities were reported to be gasoline, hexane, isopropanol, naphtha, and toluene. No tire plant has more than four separate bead dipping operations. Some units have individualized ventilation systems. For these, the average exit gas flow rate per unit is approximately 2.7 cubic meters per second. The average VOC emission factor for bead dipping is 8.2 grams per tire.

2.1.3 Tire Building

Bias-ply passenger car and truck tires are built as cylinders on a collapsible rotating drum. (Radial tires and large off-the-road tires require different building equipment or techniques.) First, the inner liner, which makes the finished tire airtight, is wrapped around the drum, followed by the layers of cord. Next, the edges of the cord fabric are folded over the beads to secure them to the tire. Then, the fabric, steel, or glass fiber belts are laid onto the cord. Finally, the tread is placed over the cords and belts and wrapped around the beads.

Rubber cement containing organic solvents such as gasoline, heptane, hexane, isopropanol, methanol, naphtha, or toluene[25,26,27,28,29] is used during this building process to tackify the rubberized tire components. An average VOC emission factor for tire assembly is 33 grams per tire. Table A-5 presents emission and operating data for actual tire building. Table 2-4 presents summary emission data and operating parameters for existing tire plants. Table 2-5 presents emission data and operating parameters for an average 16,000 tire per day manufacturing plant.

The discussion so far has described a typical bias tire manufacturing process and as it applies to the production of passenger tires. There are, however, several variations.

Truck and industrial tires generally have a higher ratio of natural to synthetic rubber than passenger tires. Natural rubber is much harder than synthetic and usually requires more solvent to render it tacky. There are also major differences in the building and molding of larger tires. For example, assembly of "off-the-road" tires may require the efforts of a two man team, two or three shifts, where as a passenger tire can be assembled in 5 minutes or less. Larger tires are also cured in molds so large that they are not usually automatically operated. Radial tires, like truck tires, contain more natural rubber. However, emission sources for radial tire manufacture are similar to those for the bias passenger tire, i.e., emissions principally come from the evaporation of solvent contained in the rubber cement and mold release sprays.

2.1.4 Tread End Cementing

Tread end cementing is the operation of applying cement to tread ends. This may be performed in two ways. In the first, the ends are automatically sprayed with cement after undertread cementing and prior to stacking in trays and transport to tire building. In the second, cement is manually applied to the ends of the rubber to splice them together after the tread is wrapped around the tire building drum. The drum is then collapsed and the green tire is removed. White gasoline, hexane, isopropanol, naphtha, and toluene are typically used for tread end cementing.[30,31,32,33,34] An average VOC emission factor for tread end cementing is 15 grams per tire. Table A-6 presents emission data for actual tire plant tread end cementing operations. Table 2-4 presents summary emission data and operating parameters for existing tire plants. Table 2-5 presents emission data and operating parameters for an average 16,000 per day manufacturing plant.

2.1.5 Green Tire Spraying

Before molding and curing, "green" tires are sprayed, inside and out, with release agents which help to remove air from the tire during molding and prevent the tire from sticking to the mold after curing. Either organic-based or water-based sprays can be used.[35] Water-based sprays yield a significant reduction in volatile organic compound emissions from green tire spraying; this alternative is discussed further in Sections 3.1 and 3.2.

Table A-7 summarizes emission data and operating parameters for green tire spraying. The average VOC emission factor from these data is 100 grams per tire. Table 2-9 presents emission data and operating parameters for an average plant.

2.1.6 Molding and Curing

Passenger car tires are molded and cured in automatic presses. A rubber bladder is inflated inside the tire, causing it to assume the characteristic toroidal shape. As the bladder inflates, the mold is closed. Steam heat is applied to the outside of the tire through the mold and to the inside through the bladder. After a timed, temperature-controlled cure, the bladder is deflated and the tire is removed from the mold. Curing usually takes 20 to 60 minutes at a temperature of 100°C to 200°C.[36] After removal from the mold, cured tires are inflated and allowed to cool.

Four tire plants[37,38] provided sufficient data to estimate the emissions of volatile organic compounds from curing. The emission factor is 2.0 grams per tire from these data. This compares favorably to the value of 2.2 grams per tire using the modified Rappaport equiation when a temperature of 150°C and a tire mass of 11.4 kilograms is assumed (see Appendix B).

2.1.7 Finishing

After the tires have cooled, any excess rubber which escaped through "weepholes" in the mold is ground off. Final buffing and grinding of the tire is performed to insure balance. White side wall tires have the black rubber protective strip ground away. The white wall receives a protective blue or green water base protective coating to minimize scruffing during shipping and mounting on rims. Some tires may receive decals, or other manufacturer markings prior to inspection and shipping. These operations may involve solvent-based inks, paints, or sprays.

Volatile organic compound emissions from finishing were calculated[39,40,41,42,43] and the resulting values are given in Table 2-6. The average VOC emission factor for tire finishing was calculated to be 5.7 grams per tire.

TABLE 2-6. EMISSIONS DATA FOR FINISHING[17,18,19,20,21]

Plant code	Calculated VOC emissions, metric tons/year	Plant code	Calculated VOC emissions, metric tons/year
A		EE	0.7
B		FF	1.1
C	17.1	GG	31.4
D	23.7	HH	3.0
E	1.2	JJ	99.1
I		LL	
K	17.9	NN	12.8
L		OO	8.6
M	1.4	PP	
O		QQ	
P	8.5	RR	9.8
Q		SS	11.3
R		TT	16.0
T	17.2	UU	14.9
V		WW	
W		XX	43.8
X		YY	
Y	116.5	ZZ	
Z		AAA	1.1
BB	3.3	BBB	
DD		CCC	2.6

[a]Blanks indicate that annual mass of VOC emissions could not be calculated.

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3.0 APPLICABLE SYSTEMS OF EMISSION CONTROL

Thic chapter reviews air pollution control technology applicable to four major VOC emission sources within the tire manufacturing industry. The emission sources addressed are: (1) undertread cementing, (2) tread end cementing, (3) bead preparation, and (4) green tire spraying. These are large VOC emission sources and the emissions are the direct result of solvent evaporation. Emissions from tire building, compounding, milling, and curing are not addressed at present.

3.1 UNDERTREAD CEMENTING

3.1.1 Summary of Control Technology

Affected Facility	Control System or Strategy	Expected Percent Capture	Percent Control of Captured Emissions
Undertread Cementer	Carbon Adsorption	85	95
	Incineration	85	90

3.1.2 General Description

In this operation, rubber cement is applied to tackify the underside of tire tread before it is sent to the tire building operation. The VOC emissions may be reduced by two techniques: adsorption and incineration. Adsorption is the only method currently being used and it is only used at one tire plant. This control system, a retrofit, consists of a capture hood and a standard dual bed carbon adsorber. The hood is designed to capture evaporating solvent from cement holding tanks, carpet rolls, and the tread stock as it moves along the conveyor. Armstrong estimated that the hood system resulted in an estimated 80 percent capture efficiency,[1] even though it was retrofitted to a tire line constructed in 1968. The capture efficiency is limited to relatively low value in the retrofit installation by the length of conveyor available for hooding. The hood is short and residence time of the tread in the hood likewise short. The overall efficiency of this installation is estimated to be about 80 percent (95 percent carbon adsorption and 85 percent capture efficiency). Because of down time and control equipment and other system inadequacies, the efficiency over the past 3 years ranged from 30-75 percent.[1b]

The hood system is designed to provide: (1) adequate dilution, to 25 percent LEL, of volatile organic compound vapors; (2) maximum residence time of cement sprayed tread in the hood; and (3) operator accessability to areas within the hood for tread changes (startup) and scheduled maintenance. For the reasons discussed above, older plants may not be able to install a 100 percent efficient capture hood.

The plant with the carbon adsorber also investigated the feasibility of incineration. On a comparative cost basis, adsorption and incineration result in essentially the same annual costs, assuming continuous operation of the undertread cementer. However the cost of incineration increases because of an eight hour period daily when the undertread cementer is not operating, resulting in reduced solvent evaporation. Additional fuel would be needed to incinerate the lower VOC gas stream during the period of low solvent evaporation. During periods of reduced solvent evaporation, longer periods of adsorption would result with less frequent stripping of the carbon. This would result in a decrease in steam and water costs to operate the adsorption system. For these reasons, adsorption control has a definite cost edge over incineration, even without a credit for recovered solvent.

Both thermal and catalytic incineration have been used in the rubber industry to control VOC emissions.[2,3] Both technologies should be transferrable to emission sources having similar VOC concentrations and exhaust flow rates.

Thermal incineration is used at a plant producing braided rubber hose.[2] A solvent (toluene) based cement is applied to the outermost textile cover to improve bondage and obtain desirable surface properties. The hose is then passed through a drying oven where solvent is evaporated. The exhaust gas is vented to the thermal incinerator. A destruction efficiency of 91 percent is reported.

In another hose plant, a braided polyester cord is passed through a cement dip tank. The cord is then passed through a drying oven prior to being woven around unvulcanized rubber hose. The oven exhaust gases are then heated to 260°C (500°F) and catalytically incinerated. The removal efficiency ranges between 90 and 94 percent, which is similar to that obtained in the thermal incinerator described above.

Incineration has also been used to control VOC emissions of similar concentrations in other industries.

3.2 TREAD END CEMENTING

3.2.1 Summary of Control Technology

Affected Facility	Control System or Strategy	Expected Percent Capture	Percent Control of Captured Emissions
Tread End Cementer	Carbon Adsorption	85	95
	Incineration	85	90

3.2.2 General Description

Emissions from tread end cementing are similar to undertread cementing. However, only about 10 percent of the cement is used and exhaust flow rates are generally about 50 percent higher than undertread cementing. Therefore, the concentration of VOC in tread end cementing exhausts is approximately 10 percent of that in undertread cementing. In this operation rubber cement is applied to the ends of tire tread before tire building. VOC emissions may again be reduced by two techniques, adsorption and incineration, although neither has been employed by the industry.

An emission capture system is again used to provide: (1) adequate dilution to VOC vapors, (2) maximum residence time of cement sprayed tread in the hood, (3) operator accessability to areas within the hood for tread change and scheduled maintenance, and (4) maximum collection efficiency.

For this process step, operating procedures and equipment arrangement vary considerably from plant to plant. Because of this there is a great difference between plants in the volume and concentration of the VOC vapors collected, even by well designed capture systems. In some plants a combination of large air volume and low VOC concentration may make retrofit emission control expensive in relation to benefit.

3.3 BEAD DIPPING

3.3.1 Summary of Control Technology

Affected Facility	Control System or Strategy	Expected Percent Capture	Percent Control of Captured Emissions
Bead Dip Tank	Carbon Adsorption	85	95
	Incineration	85	90

3.3.2 General Description

Neither adsorption nor incineration has been used by the industry to control VOC emissions from bead dipping. However, thermal and catalytic incineration have been reported as methods of controlling VOC emissions from fabric cementing in the rubber hose manufacture industry.[5,6] Both should be transferrable to bead cementing in the tire industry. The gas stream and concentrations are similar and should provide confidence in applicability of control. Both thermal and catalytic incineration as used in the rubber hose industry to control VOC emissions are discussed in Section 3.2.2.

As in tread end cementing above, operating procedures and equipment variations between plants cause a difference in the volume and concentration of the VOC vapor collected, even by well designed capture systems. In some plants a combination of large air volume and low VOC concentration may make retrofit emission control expensive in relation to benefit.

3.4 GREEN TIRE SPRAYING

3.4.1 Summary of Control Technology

Affected Facility	Control System or Strategy	Expected Percent Capture	Percent Control of Captured Emissions
Green Tire Spray Booth	Water Based Sprays	NA	NA
	Carbon Adsorption	90	95
	Incineration	90	90

3.4.2 General Description

In this operation a solvent-based mold release compound is applied to both the inside and outside of a green tire before the tire is cured. VOC emissions may be reduced by three techniques: change to water-based sprays, adsorption, and incineration. Neither adsorption nor incineration has been employed by the industry to control VOC emissions from green tire spraying. Incineration would be applicable to this source by applying the technology as used to control similar sources as discussed in Section 3.2.2. At least six plants manufacturing passenger tires have switched to water-based sprays. One manufacturer estimated a cost penalty of three cents per tire when using water-base sprays.[7]

Organic solvents such as heptane, hexane, and toluene are contained in the mold release sprays that are used within the industry. Such solvent-based formulations can be replaced by water-based sprays, available from commercial sources. These water based mixtures eliminate VOC emissions from the spraying of both the inside and outside of green tires.

Water-based inside sprays are available from Dow Corning Corporation, General Electric Company, and SWS Silicones Corporation. These sprays, containing no organic solvents, are aqueous dispersions of silicone solids.

Typical compositions are: solids, 30-60 percent by weight; water, 35 to 60 percent; nonionic emulsifiers, 3 to 4 percent; bactericides, less than 1 percent; and corrosion inhibitors, less than 1 percent. Individual commercial supplier specifications for inside tire sprays are summarized in Table 3.1. In addition, mica is added sometimes to further promote mold release.

Water-based outside sprays contain approximately 35 weight percent solids, most of which is carbon black, and are available from SWS Silicones Corporation.

TABLE 3-1. Composition of Water-Based Inside Tire Sprays[8,9]

Supplier	Component	Amount, weight percent
Dow Corning Corporation	Solids	60
	Water	-[a]
	Emulsifiers[b]	-[a]
General Electric Company	Solids[c]	50
	Water	~45
	Emulsifiers[d]	3-4
	Bactericide[e]	<1
	Corrosion inhibitor[f]	<1
SWS Silicones Corporation	Solids[g]	35-60
	Water	-[a]
	Emulsifiers[b]	-[a]

[a]Amount not specified.

[b]Composition not specified.

[c]Polydimethylsiloxane.

[d]Ethoxylated alkylphenols.

[e]6-acetoxy-2,2-dimethyl-*m*-dioxane.

[f]Sodium benzoate.

[g]Polydimethylsiloxane, other silicone compounds, and/or mica.

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4.0 COST ANALYSIS

4.1 INTRODUCTION

4.1.1 Purpose

The purpose of this chapter is to present capital and annualized costs associated with control of volatile organic compound (VOC) emissions from selected processes and operations in the tire manufacturing industry. An analysis of cost-effectiveness is included to provide a comparison of the various control alternatives.

4.1.2 Scope

Estimates of capital and annualized costs are developed for control of VOC emissions from undertread cementing, bead dipping, tire building, tread end cementing, and green tire spraying. Industry sources not addressed include compounding, milling, calendering, extrusion, and curing. Estimates are limited to the sources and control systems shown in Table 4-1.

4.1.3 Model Plants Parameters

Costs were developed for a model tire plant producing 16,000 tires per day. The plant parameters are estimates from technical information gathered by others during the development of this document. Although projecting costs of pollution control for a model plant yield results that may differ from actual costs, this procedure offers the best means of comparing relative costs and cost-effectiveness of various control measures.

4.1.4 Bases for Capital Cost Estimates

Capital costs represent the investment required to retrofit a control

TABLE 4-1. VOC EMISSIONS SOURCES AND CONTROL SYSTEMS

Emission sources	Control systems
Undertread cementing	Incineration Carbon adsorption
Bead dipping	Incineration Carbon adsorption
Tire building	Incineration Carbon adsorption
Tread end cementing	Incineration Carbon adsorption
Green tire spraying	Incineration Carbon adsorption Water-based spray

system, including basic collection devices and auxiliary equipment, installation, contingencies, and taxes. Estimates of capital costs are based on data reported in Section 12 of Reference 1, except that the cost of water-based sprays used in green tire spraying was obtained from a representative of the Armstrong Tire Co.[2,3] The data from Reference 1 concern the costs of controlling VOC emissions from tire building, green tire spraying, and undertread and tread end cementing. All capital costs are expressed in January 1978 dollars. Table 4-2 lists the items included in the capital costs of retrofitted control systems.

4.1.5 Bases for Annualized Cost Estimates

Annualized costs are those associated with operation and maintenance of the control systems and with recovery of capital investment. Operating costs include the cost of materials consumed or used in operating the control system, utilities, and normal maintenance. As in the case of capital cost, the data utilized come from References 1, 2, and 3 and are adjusted to January 1978 dollars. Table 4-3 lists the items included in annualized costs.

4.2 CONTROL OF VOC EMISSIONS FROM SELECTED FACILITIES

4.2.1 Parameters of Model Plants

Table 4-4 presents the technical parameters of facilities in a typical tire manufacturing plant. The listed production rates, VOC emission rates, exhaust rates, and VOC concentrations in the exhaust gas are average values, not those of a specific facility.

Three main systems to control VOC emissions from the listed facilities are discussed for all purposes within the scope of this chapter. These systems are thermal incineration, catalytic incineration, and carbon adsorption. In addition, a change from solvent to water-based sprays is considered as a

TABLE 4-2. ITEMS INCLUDED IN CAPITAL COSTS OF RETROFITTED CONTROL SYSTEMS

Basic collection equipment

Auxiliary equipment

- Air movement equipment

    - Fans and blowers
    - Hoods, ducts
    - Electrical motors, starters, wire conduits, switches, etc.

- Liquid movement equipment

    - Pumps
    - Electrical motors, starters, wire conduits, switches, etc.
    - Pipes and valves
    - Settling tanks

- Instrumentation to measure and control:

    - Air and/or liquid flow
    - Natural gas and/or fuel oil flow
    - Temperature and/or pressure
    - Operation and capacity
    - Power

Research and development, including stream measurement, pilot plant operations, and personnel costs

Installation

- Labor
- Cleaning the site
- Yard and underground work
- Building modifications
- Inspection
- Support construction
- Protection of existing facilities
- Supervision and engineering
- Startup

Storage and disposal equipment

Contingencies

Sales tax

TABLE 4-3. ITEMS INCLUDED IN ANNUALIZED COSTS OF RETROFITTED CONTROL SYSTEMS

Capital charges
Operating costs
Utilities needed to operate control equipment
Materials consumed, such as fuel, in operating the control system
Waste disposal operations
Overhead
Property taxes
Insurance
Maintenance costs
Replacement of parts and equipment
Supervision and engineering
Repairs
Lubrication
Surface protection, such as cleaning and painting
Offsetting cost benefits from operating control system (such as recovery of valuable byproduct)

TABLE 4-4. PARAMETERS FOR A TYPICAL PLANT MANUFACTURING 16,000 tires/day

Facility	Number of processing units	Production rate, tires/day per unit	VOC emission rate, kg/day per unit	Total VOC, kg/day	Exhaust gas flow rate, m^3/s per facility	(ft^3/min per facility)	VOC concentration of exhaust gas, g/m^3	(ppm[a])	Exhaust gas temperature, °C
Undertread cementing	4	4020	380	1520	2.8	(23,600)	1.57	(385)	20
Bead dipping	2	8050	65	130	2.7	(11,400)	0.28	(69)	20
Tire building	50	320	10	500	5.7	(600,000)	0.02	(5)	20
Tread end cementing	4	4020	60	240	3.9	(32,800)	0.18	(44)	20
Green tire spraying	5	3220	320	1600	4.6	(48,400)	0.81	(200)	20

[a] Calculation based on an average molecular weight of 100.

method of pollution control for green tire spraying. Depending on the facility, the efficiency of these control options ranges from 59 to 97 percent.

Tables 4-5 and 4-6 list the assumptions behind the cost estimates in Reference 1 for catalytic and thermal incinerators and carbon adsorption systems. The cost analysis is based solely on the model plant parameters, the data from Reference 1, and the assumptions listed.

4.2.2 Costs of Control

Data concering each of the three main control systems were abstracted from Reference 1, plotted on log-log paper, and subjected to a least-squares fit; and curves were constructed for both annualized and capital costs versus the exhaust flow rate for each system. The exhaust volumes specified in Table 4-4 were used to estimate capital and annualized costs for all the combinations of main control systems and facilities. Tables 4-7 through 4-11 present the estimates. Table 4-9 also lists costs of using water-based sprays in green tire spraying.

Because the estimated costs of gas cleaning pertain to specific exhaust stream conditions, cost factor assumptions, and facility sizes, costs could increase or decrease with a change in parameters. For example, 90 percent reduction of VOC emissions from an undertread or tread end cementer might require additional expenditures for enclosing and/or extending the conveyor, increasing the duct work, and using a larger fan motor to ensure adequate solvent capture during drying.

Each cost given in Tables 4-7 through 4-11 represents the total costs for manifolding all operating units in each facility. Thus, the control option costs in Table 4-7 represent the cost of treating exhaust gases from four undertread cementers with one piece of control equipment. This treatment

TABLE 4-5. ASSUMPTIONS USED IN DEVELOPING COST ESTIMATES FOR CATALYTIC AND THERMAL INCINERATORS[1]

Catalytic incinerator assumptions:

- Designed for natural gas and propane operation
- Capable of operation at 425°C (800°F) below 6% lower explosive limit (LEL) at 650°C (1200°F) from 6% to 25% LEL
- Catalyst life, 3 years

The catalytic afterburner was costed on two design bases: 425°C (800°F) and 650°C (1200°F). The higher temperature design is required for LEL levels exceeding 6%. At a 6% LEL condition and a minimum initiation temperature of 315°C (600°F), the outlet temperature of the catalyst is approximately 425°C (800°F). At a 25% LEL condition and a minimum initiation temperature of 260°C (500°F), the outlet temperature of the catalyst is around 650°C (1200°F).

Thermal incinerator assumptions:

- Designed for oil and natural gas operation
- Capable of operation at 815°C (1500°F)
- Residence time, 0.5 s
- Nozzle mix burner capable of firing No. 2 through No. 6 oil
- Forced mixing of the burner combustion products by a slotted-cylinder mixing arrangement (The cylinder allows the burner flame to establish itself before radial entry of the effluent through slots in the far end of the cylinder.)
- Ducting a portion of the effluent to the burner to be incinerated and serve as combustion air (Such ducting allows the burner to act as a raw gas burner and saves fuel, compared with conventional nozzle mix burners. This design, however, can only be used when the oxygen content of the oven exhaust is 17% or more by volume.)

Common assumptions:

- Outdoor location
- Rooftop installation requiring structural steel
- Fuel cost of $1.45/GJ ($1.50/million Btu) gross

  (Correction factors are provided to determine operating costs at higher fuel prices.)

(continued)

TABLE 4-5 (continued)

- Electricity cost of $0.03/kWh
- Depreciation and interest, 16% of capital costs; annual maintenance, 5% of capital costs; taxes and insurance, 2% of capital costs; building overhead, 2% of capital costs.
- Direct labor cost: 0.5 h/shift x 730 shifts/yr x $8 = $2920/yr
- Operating time: 2 shifts/day x 8 h/shifts x 365 days/yr = 5840 h/yr

TABLE 4-6. ASSUMPTIONS USED IN DEVELOPING COST ESTIMATES FOR CARBON ADSORBERS[1]

Fuel cost of $1.42 GJ ($1.50/million Btu)
Electricity cost of $0.03/kWh
Activated carbon cost of $1.50/kg ($0.68/lb)
Water cost of $10.57/m^3 ($0.04/10^3 gal)
Steam cost of $4.40/Mg ($2/10^3 lb)
Life of activated carbon, 5 yr
Adsorber operating temperature of 38°C (100°F)
Market value (December 1975) of benzene = $0.23/liter ($0.85/gal)
Market value (December 1975) of hexane = $0.12/liter ($0.47/gal)
Normal retrofit situation
Direct labor cost: 0.5 h/shift x 730 shifts/year x $8/h = $2920/yr
Annual maintenance, taxes, insurance, building overhead, depreciation, and interest on borrowed money: 25% of capital costs investment
Operating time of 5840 h/yr

TABLE 4-7. ESTIMATED CAPITAL COSTS, ANNUALIZED COSTS, AND COST-EFFECTIVENESS OF CONTROL SYSTEMS FOR UNDERTREAD CEMENTING[a]
(thousands of January 1978 dollars, except as noted)

Control systems[b]	Capital costs,			Annualized costs,			Cost-effectiveness,[c]	
	Total	Per m^3/s	(Per scfm)	Total	Per m^3/s	(Per scfm)	\$/Mg	(\$/ton)
Catalytic incineration								
No heat recovery	130	12	(0.006)	160	14	(0.007)	289	(262)
Primary heat recovery	180	16	(0.008)	115	10	(0.005)	208	(188)
Primary and secondary heat recovery	210	19	(0.019)	92	8	(0.004)	166	(150)
Thermal incineration								
No heat recovery	130	12	(0.006)	280	25	(0.012)	505	(458)
Primary heat recovery	160	14	(0.007)	255	23	(0.011)	460	(417)
Primary and secondary heat recovery	170	15	(0.007)	115	10	(0.005)	208	(188)
Carbon adsorption								
No credit for recovered solvent	340	30	(0.014)	175	16	(0.007)	316	(286)
Recovered solvent credited at fuel value	340	30	(0.014)	155	14	(0.007)	280	(254)
Recovered solvent credited at market value	340	30	(0.014)	100	9	(0.004)	180	(164)

[a] Based on an exhaust gas flow rate of 11.2 m^3/s (23,600 cfm) for four units and a VOC emission rate of 1520 kg/day for four units.
[b] All control systems are assumed to reduce VOC emissions by 90 percent.
[c] The amount of solvent controlled per year is 554 Mg (611 ton). ← this is uncontrolled emission

TABLE 4-8. ESTIMATED CAPITAL COSTS, ANNUALIZED COSTS AND COST-EFFECTIVENESS OF CONTROL SYSTEMS FOR BEAD DIPPING[a]
(in thousands of January 1978 dollars, except as noted)

Control systems[b]	Capital costs,			Annualized costs,			Cost-effectiveness,[c]	
	Total	Per m^3/s	(Per scfm)	Total	Per m^3/s	(Per scfm)	\$/Mg	(\$/ton)
Catalytic incineration								
No heat recovery	115	21	(0.010)	110	20	(0.010)	2300	(2100)
Primary heat recovery	145	27	(0.013)	80	15	(0.007)	1680	(1500)
Primary and secondary heat recovery	165	30	(0.014)	70	13	(0.006)	1480	(1340)
Thermal incineration								
No heat recovery	120	22	(0.010)	165	31	(0.014)	3400	(3160)
Primary heat recovery	145	27	(0.013)	140	26	(0.012)	2950	(2680)
Primary and secondary heat recovery	160	30	(0.014)	110	20	(0.010)	2300	(2100)
Carbon adsorption								
No credit for recovered solvent	250	46	(0.022)	985	182	(0.087)	20,800	(18,800)
Recovered solvent credited at fuel value	250	46	(0.022)	860	160	(0.076)	18,100	(16,400)
Recovered solvent credited at market value	250	46	(0.022)	620	115	(0.055)	13,100	(11,800)

[a] Based on an exhaust gas flow rate of 5.4 m^3/s (11,372 cfm) for two units and a VOC emission rate of 130 kg/day for two units.

[b] All control systems are assumed to reduce VOC emissions by 90 percent.

[c] The amount of solvent controlled per year is 47.4 Mg (52.5 ton).

TABLE 4-9. ESTIMATED CAPITAL COSTS, ANNUALIZED COSTS, AND COST-EFFECTIVENESS OF CONTROL SYSTEMS FOR TIRE BUILDING[a,b]
(in thousands of January 1978 dollars, except as noted)

Control systems[c]	Capital costs,			Annualized costs,			Cost-effectiveness,[d]	
	Total	Per m^3/s	(Per scfm)	Total	Per m^3/s	(Per scfm)	$/Mg	($/ton)
Catalytic incineration								
No heat recovery	1500	5.3	(0.003)	2500	8.8	(0.004)	137,000	(124,000)
Primary heat recovery	2300	8.0	(0.004)	1800	6.3	(0.003)	97,000	(90,000)
Primary and secondary heat recovery	2750	9.6	(0.005)	1250	4.4	(0.002)	68,000	(62,000)
Thermal incineration								
No heat recovery	1600	5.6	(0.003)	5200	18.3	(0.009)	285,000	(268,000)
Primary heat recovery	1750	6.1	(0.003)	5600	19.6	(0.009)	306,000	(280,000)
Primary and secondary heat recovery	2000	7.0	(0.003)	3000	10.5	(0.005)	164,000	(149,000)
Carbon adsorption								
No credit for recovered solvent	4750	16.6	(0.008)	3800	13.3	(0.006)	208,000	(189,000)
Recovered solvent credited at fuel value	4750	16.6	(0.008)	3100	10.9	(0.005)	170,000	(154,000)
Recovered solvent credited at market value	4750	16.6	(0.008)	1800	6.3	(0.003)	98,000	(89,000)

[a] Based on an exhaust gas flow rate of 285 m^3/s (600,000 cfm) for 50 units and a VOC emission rate of 500 kg/day for 50 units.

[b] The 50 units for tire building are divided into 10 groups of 5 units.

[c] All control systems are assumed to reduce VOC emissions by 80 percent.

[d] The amount of solvent controlled per year is 18.25 Mg (201 ton).

TABLE 4-10. ESTIMATED CAPITAL COSTS, ANNUALIZED COSTS, AND COST-EFFECTIVENESS OF CONTROL SYSTEMS FOR TREAD END CEMENTING[a]
(in thousands of January 1978 dollars, except as noted)

Control systems[b]	Capital costs,			Annualized costs,			Cost-effectiveness,[c]	
	Total	Per m^3/s	(Per scfm)	Total	Per m^3/s	(Per scfm)	$/Mg	($/ton)
Catalytic incineration								
No heat recovery	135	8.7	(0.004)	180	11.5	(0.005)	2000	(1800)
Primary heat recovery	185	11.9	(0.006)	130	8.3	(0.004)	1480	(1340)
Primary and secondary heat recovery	230	14.7	(0.007)	100	6.4	(0.003)	1140	(1000)
Thermal incineration								
No heat recovery	140	9.0	(0.004)	340	22	(0.010)	3880	(3500)
Primary heat recovery	160	10.3	(0.005)	340	22	(0.010)	3880	(3500)
Primary and secondary heat recovery	180	11.6	(0.005)	210	13.5	(0.006)	2300	(2200)
Carbon adsorption								
No credit for recovered solvent	375	24	(0.011)	230	14.7	(0.007)	2600	(2400)
Recovered solvent credited at fuel value	375	24	(0.011)	195	12.5	(0.006)	2200	(2000)
Recovered solvent credited at market value	375	24	(0.011)	125	[illegible].0	(0.004)	1400	(1300)

[a] Based on an exhaust gas flow rate of 15.6 m^3/s (32,853 cfm) for four units and a VOC emission rate of 240 kg/day for four units.

[b] All control systems are assumed to reduce VOC emissions by 90 percent.

[c] The amount of solvent controlled per year is 87.6 Mg (96.4 ton).

Uncontrolled

TABLE 4-11. ESTIMATED CAPITAL COSTS, ANNUALIZED COSTS, AND COST-EFFECTIVENESS OF CONTROL SYSTEMS FOR GREEN TIRE SPRAYING[a]
(in thousands of January 1978 dollars, except as noted)

Control systems[b]	Capital costs,			Annualized costs,			Cost-effectiveness,[c]	
	Total	Per m^3/s	(Per scfm)	Total	Per m^3/s	(Per scfm)	$/Mg	($/ton)
Catalytic incineration								
No heat recovery	145	6.3	(0.003)	220	9.6	(0.005)	377	(342)
Primary heat recovery	220	9.6	(0.005)	160	7.0	(0.003)	274	(250)
Primary and secondary heat recovery	260	11.3	(0.005)	118	5.1	(0.002)	202	(184)
Thermal incineration								
No heat recovery	150	6.5	(0.003)	450	19.5	(0.009)	770	(700)
Primary heat recovery	175	7.6	(0.004)	490	21.3	(0.010)	839	(763)
Primary and secondary heat recovery	200	8.7	(0.004)	270	11.7	(0.006)	462	(420)
Carbon adsorption								
No credit for recovered solvent	450	19.5	(0.009)	325	14.1	(0.007)	556	(584)
Recovered solvent credited at fuel value	450	19.5	(0.009)	270	11.7	(0.006)	462	(420)
Recovered solvent credited at market value	450	19.5	(0.009)	160	6.95	(0.003)	274	(250)
Water-based spray	15[d]	NA	NA	123	NA	NA	210	(192)

[a] Based on an exhaust gas flow rate of 23 m^3/s (48,400 cfm) for five units and a VOC emission rate of 1600 kg/day for five units.

[b] All control systems are assumed to reduce VOC emission by 80 percent.

[c] The amount of solvent controlled per year is 584 Mg (642 ton).

[d] This investment of capital money is required in only some cases.

NA - Not applicable.

would require manifolding of the four units to the control system. The tire building facility contains 50 units producing a total exhaust gas flow rate of 600,000 ft^3/min, which is much larger than can be handled by a single control device. Therefore, the 50 tire builders were manifolded into groups of 5 and exhausted to 10 control devices. This design yields a flow rate of 60,000 ft^3/min to each control device. In Table 4-9, therefore, each control system was costed at 60,000 ft^3/min; and this cost was multiplied by 10 to yield the total cost for tire building.

The use of water-based mold release agents in green tire spraying represents a process change. This change normally does not involve any additional capital expenditures over that required for spraying solvent-based agents. In some instances, however, expenditures of approximately $15,000 may be required for equipment modification.[2,3] There are no additional operating or maintenance costs, except for the higher cost of the water-based spray. This amounts to approximately $0.03 per tire for direct annualized costs. The indirect annualized costs for this control option are based on a capital recovery factor of 13.1 percent and an additional 4 percent for taxes and insurance.

16080 × 365 × .03 = $176076/yr
+ 2044
178120

4.3 COST-EFFECTIVENESS

The most cost-effective control system for all facilities is catalytic incineration with primary and secondary heat recovery. For green tire spraying, a change to water-based spraying appears to be about as cost-effective as solvent-based spraying. Because no large capital investment is required and because there are more tax benefits for an expense item than a capital item, water-based sprays appear more economically attractive. In all cases, the most expensive option is thermal incineration because of the high costs of fuel.

4.4 SUMMARY

The cost analyses presented represent the costs associated with all units in a facility and are based on data contained in Reference 1, except for green tire spraying.

Catalytic incineration with primary and secondary heat recovery proved to be the most cost-effective control option for bead dipping, tire building, green tire spraying, and undertread and tread end cementing. The large expense requirements of changing to water-based sprays, however, could make this option more attractive than exhaust gas incineration for green tire spraying.

The costs of controlling VOC emissions are much higher for the tire building operations than for any other facilities; however, cost-effectiveness at such operations would be enhanced by modifying ventilation and capture systems to reduce volume and increase concentrations of VOC emissions.

REFERENCES

1. Monsanto Research Corporation. Draft Report on Identification and Control of Hydrocarbon Emssions from Rubber Processing Operations. Prepared under EPA Contract No. 68-02-1411. November 23, 1977.

2. Personal communication between R. Schummer, PEDCo Environmenta1, Inc., Cincinnati, and F.M. Lysterborgh, Armstrong Tire Co., New Haven, Conn. phone call memorandum No. 1, December 8, 1978.

3. Personal communication between R. Schummer, PEDCo Environmental, Inc., Cincinnati, and F.M. Lysterborgh, Armstrong Tire Co., New Haven, Conn. phone call memorandum No. 2, December, 8, 1978.

5.0 ADVERSE EFFECTS OF APPLYING TECHNOLOGY

5.1 AIR IMPACTS

No significant adverse impacts should result from these regulations. although negligence in maintenance and operation of control devices could increase emissions in individual cases. Examples are carbon adsorption systems operating with spent or saturated adsorbent, and excessive ventilation rates.

Boiler emissions will increase due to steam required to regenerate carbon, but these increases will be insignificant compared to reduction in VOC emissions by control equipment. There are few current measurements of oxides of nitrogen (NO_x) levels in gas streams from incinerators. In most instances these emissions will be insignificant compared to reduction in VOC emission by control equipment.

5.2 CARBON ADSORPTION CONTROL SYSTEMS

The increased energy required to operate carbon adsorption systems is a potential disadvantage. The quantity of energy will depend on the size of adsorbers and the concentrations of the solvent entering the bed. Any reduction which can be made in air flow from the capture system will permit smaller adsorbers with attendant reductions in energy.

Proper maintenance and operation of carbon adsorption systems are necessary to ensure effective significant reductions in VOC emissions. Carbon adsorption systems should be equipped with instrumentation to time regeneration cycles. The cycle should be adjusted to start before breakthrough occurs. With age, a heel of heavier organics can accumulate in the carbon, thus reducing its working capacity. Breakthrough can go undetected unless a sensing device is installed at the outlet. An indicator for most applications, sensitive to 25-75 ppm of vapor, should suffice. The breakthrough sensing device should be required to be connected to (1) a direct readout meter, (2) an alarm, bell or light, or (3) a device that initiates the regeneration cycle.

A beneficial impact of carbon adsorption control is that solvent can normally be recovered for reuse. Thus, a valuable and increasingly scarce material can be conserved. However, recovery is generally limited to water (from steam regeneration) immiscible solvents.

5.3 INCINERATION

The major disadvantage of incineration is the auxiliary fuel that is generally required. This can be partially offset when heat is recovered to preheat inlet gas streams or to use in other processes.

At the time of installation thermal and catalytic incinerators should be required to be equipped with temperature indicators. Temperature sensors should also be required on both inlet and outlet streams of catalytic units to provide a continuous indication of catalytic activity.

5.4 WATER AND SOLID WASTE IMPACT

The largest impact on water quality would result from use of carbon adsorption. Steam used to desorb the solvent is condensed with the solvent and separated by gravity. Some solvent will remain in the water and eventually enter the sewer system.

There appears to be no significant solid waste impact resulting from the control of VOC from tire manufacturing. The only problem could arise from carbon. Carbon used in carbon adsorption beds is discarded periodically. Vendors and users have estimated the life of carbon at up to 30 years but replacement is generally recommended every 10 to 15 years.

APPENDIX A

Table A-1. TOTAL VOLATILE ORGANIC COMPOUND EMISSIONS FROM THE MANUFACTURING PLANTS[2,3,4,12-21]

Plant code	Calculated VOC emissions, metric tons/year	Plant code	Calculated VOC emissions, metric tons/year
A	1,042	EE	963
B	33	FF	209
C	567	GG	1,564
D	962	HH	1,342
E	774	JJ	1,334
I	852	LL	4,387
K	1,296	NN	624
L	249	OO	856
M	2,578	PP	385
O	1,719	QQ	1,213
P	1,341	RR	476
Q	1,371	SS	673
R	1,218	TT	1,334
T	712	UU	1,032
V	1,705	WW	1,719
W	266	XX	1,287
X	1,025	YY	1,058
Y	1,188	ZZ	202
Z	1,646	AAA	605
BB	56	BBB	743
DD	790	CCC	223

In order to calculate the masses of VOC emissions given in Table A-1, densities of specific organic compounds[22] were used to convert reported solvent consumption in gallons to mass. The following assumptions were made: (1) the density of naphtha and any "rubber solvents" of unspecified composition is 645 kg/m^3,[23] and (2) the density of gasoline is equal to that of octane, 702.5 kg/m^3.[22] No solvent was assumed to remain in the final tire product.

APPENDIX A-2 CALCULATIONS FOR ANNUAL MASS VOC EMISSIONS

$$\text{Confidence Limit} = \pm \frac{t_{\alpha/2,\ \gamma}\ s_x}{\sqrt{n}} \left(\frac{N-n}{N-1}\right)^{1/2} \qquad (1)$$

where $t_{\alpha/2,\ \gamma}$ = Student's t value for 100 $(1-\alpha)$ percent confidence limits and γ degrees of freedom

s_x = standard deviation

n = number of samples

N = size of total population

The number of degrees of freedom for this case is 41, which is equal to the number of samples, n (i.e., 42 from Table 3-4), minus one. The size of the total population of tire manufacturing plants is 62 (from the number of plants listed in Table 3-1). For 95 percent confidence, $t_{0.05/2,\ 41}$ can be approximated by $t_{0.025,\ \infty}$, which equals 1.960.[24] Therefore, the 95% confidence limits for the mean annual mass of VOC emisions per tire manufacturing plant are:

$$\pm \frac{(1.960)(755)}{\sqrt{42}} \left(\frac{62-42}{62-1}\right)^{1/2} = \pm 131\ \frac{\text{metric tons}}{\text{year}} \qquad (2)$$

To obtain the mean VOC emission factor on a mass-per-tire basis[a] with the appropriate confidence limits, the above values are divided by the average tire production per plant, which is 16,100 tires per operating day, or 3,563,000 tires per year, using data from Tables 3-1 and 3-2. The mean VOC emission factor and its 95 percent confidence limits are thus 291 ± 37 grams per tire. Therefore, total emissions of volatile organic compounds due to solvent consumption by the tire industry in the United States can be estimated to be between 56,300 and 72,500 metric tons per year.

[a] Emission factors were calculated on this basis because the majority of plants responding to the Section 114 survey provided production data in terms of the number, not the mass, of tires produced. Although VOC emissions per tire will be greater for larger, more massive tires such as those used for trucks and buses, the calculated confidence limits will encompass 95 percent of the possible values.

TABLE A-3. EMISSIONS DATA FOR UNDERTREAD CEMENTING[2,3,4,12-21]

Plant code	Number of undertread cementing lines	Exit gas properties: Flow rate, m^3/s per line — Average	Exit gas properties: Flow rate, m^3/s per line — Range	Exit gas properties: Temperature, °C	Exit gas properties: Gauge pressure, Pa	Calculated VOC emissions, metric tons/year
A	-[a]	-[b]	-[a]	-[a]	-[a]	-[b]
B	-[a]	-[b]	-[a]	-[a]	-[a]	-[b]
C	2	1.5	0.6-2.4	-[c]	530-800	203
D	3	2.0	-[d]	-[c]	0	296
E	4	2.8	1.2-4.4	-[c]	0	494
I	2	2.6	-[d]	-[c]	0	189
K	2	3.8	-[d]	-[c]	0	305
L	-[a]	-[b]	-[a]	-[c]	0	15
M	-[a]	-[b]	-[a]	-[a]	-[a]	-[b]
O	-[a]	-[b]	-[a]	-[a]	-[a]	-[b]
P	3	1.9	-[d]	-[c]	530	586
Q	-[a]	-[b]	-[a]	-[a]	-[a]	197
R	3	2.5	-[d]	-[c]	0	361
T	8	3.6	1.9-3.8	-[c]	130	641
V	8	3.8	-[d]	-[c]	-[a]	-[b]
W	2	3.3	3.2-3.5	-[c]	0	230
X	13	3.3	-[d]	-[c]	0	472
Y	1	5.7	-[e]	-[c]	0	511
Z	-[a]	-[b]	-[a]	-[a]	-[a]	-[b]
BB	-[a]	-[b]	-[a]	-[a]	-[a]	26
DD	-[a]	-[b]	-[a]	-[a]	-[a]	-[b]
EE	-[a]	-[b]	-[a]	-[a]	-[a]	248
FF	1	2.6	-[e]	-[c]	530	177
GG	4	2.8	-[d]	-[c]	-[a]	968
HH	-[a]	-[b]	-[a]	-[a]	-[a]	-[b]
JJ	2	2.4	-[d]	-[c]	800	416
LL	5	1.4	-[d]	-[c]	-[a]	236
NN	2	1.5	-[d]	-[c]	530	195
OO	-[a]	-[b]	-[a]	-[a]	-[a]	-[b]
PP	4	1.0	-[d]	25-30	0	84
QQ	-[a]	-[b]	-[a]	-[c]	0	-[b]
RR	2	2.0	1.4-2.6	-[c]	270-2,500	301
SS	2	3.2	-[d]	27	-[a]	113
TT	-[a]	-[b]	-[a]	-[a]	-[a]	479
UU	4	1.8	-[a]	-[c]	0	459
WW	3	3.8	-[d]	21	0	804
XX	-[a]	-[b]	-[a]	-[a]	-[a]	470
YY	3	4.4	-[d]	-[c]	0	758
ZZ	-[a]	-[b]	-[a]	-[c]	0	-[b]
AAA	-[a]	-[b]	-[a]	-[c]	0	94
BBB	-[a]	-[b]	-[a]	-[a]	-[a]	297
CCC	-[a]	-[b]	-[a]	-[a]	-[a]	31

[a] Not available.

[b] Not calculated.

[c] Ambient

[d] All units have same exit gas flow rate.

[e] Only one value reported.

TABLE A-4. EMISSIONS DATA FOR BEAD DIPPING[2,3,4,12-21]

Plant code	Number of bead dipping operations	Exit gas properties: Flow rate, m^3/s per operation: Average	Range	Temperature, °C	Gauge pressure, Pa	Calculated VOC emissions, metric tons/year
A	1	3.0	–[a]	–[b]	0	3.4
B	–[c]	–[d]	–[c]	–[c]	–[c]	–[d]
C	1	0.9	–[a]	–[b]	4	73.6
D	–[c]	–[d]	–[c]	–[c]	–[c]	–[d]
E	–[c]	–[d]	–[c]	–[b]	0	7.7
I	1	4.7	–[a]	–[b]	0	17.9
K	1	–[d]	–[e]	–[f]	–[f]	9.3
L	–[c]	–[d]	–[c]	–[c]	–[c]	–[d]
M	1	–[d]	–[e]	–[f]	–[f]	2.1
O	–[c]	–[d]	–[c]	–[c]	–[c]	–[d]
P	3	2.4	–[g]	–[b]	4	31.3
Q	–[c]	–[d]	–[c]	–[c]	–[c]	–[d]
R	1	3.6	–[a]	–[b]	0	106.6
T	–[c]	–[d]	–[c]	–[c]	–[c]	13.7
V	–[c]	–[d]	–[c]	–[c]	–[c]	–[d]
W	–[c]	–[d]	–[c]	–[c]	–[c]	–[d]
X	1	–[d]	–[e]	–[f]	–[f]	7.7
Y	–[c]	–[d]	–[c]	–[c]	–[c]	–[d]
Z	–[c]	–[d]	–[e]	–[f]	–[f]	4.0
BB	–[c]	–[d]	–[e]	–[f]	–[f]	–[d]
DD	–[c]	–[d]	–[c]	–[c]	–[c]	–[d]
EE	–[c]	–[d]	–[e]	–[f]	–[f]	2.4
FF	1	–[d]	–[e]	–[f]	–[f]	1.1
GG	4	–[d]	–[e]	–[f]	–[f]	–[d]
HH	–[c]	–[d]	–[c]	–[c]	–[c]	13.2
JJ	1	2.4	–[a]	–[b]	2,000	59.5
LL	–[c]	–[d]	–[c]	–[c]	–[c]	–[d]
NN	1	2.4	–[a]	–[b]	1,470	93.9
OO	2	3.3	–[a]	21	–[c]	15.8
PP	–[c]	–[d]	–[c]	–[c]	–[c]	–[d]
QQ	–[c]	–[d]	–[c]	–[c]	–[c]	–[d]
RR	1	–[d]	–[e]	–[f]	–[f]	53.2
SS	–[c]	–[d]	–[c]	–[c]	–[c]	–[d]
TT	–[c]	–[d]	–[e]	–[f]	–[f]	28.4
UU	–[c]	–[d]	–[c]	–[c]	–[c]	–[d]
WW	4	0.1	–[g]	21	0	36.6
XX	1	3.8	–[a]	–[b]	0	59.9
YY	–[c]	–[d]	–[c]	–[c]	–[c]	–[d]
ZZ	–[c]	–[d]	–[c]	–[c]	–[c]	–[d]
AAA	–[c]	–[d]	–[c]	–[c]	–[c]	–[d]
BBB	–[c]	–[d]	–[e]	–[f]	–[f]	2.3
CCC	–[c]	–[d]	–[d]	–[c]	–[c]	–[d]

[a]Only one value reported.
[b]Ambient.
[c]Not available.
[d]Not calculated.
[e]No individualized ventilation system(s).
[f]Not applicable.
[g]All units have same exit gas flow rate.

TABLE A-5. EMISSIONS DATA FOR TIRE BUILDING[2,3,4,12-21,a]

Plant code	Number of tire-building machines	Calculated VOC emissions, metric tons/year	Plant code	Number of tire-building machines	Calculated VOC emissions, metric tons/year
A		134	EE		255
B			FF	33	2
C	63	91	GG		
D		67	HH		12
E		139	JJ	61	109
I			LL		
K			NN	50	22
L		148	OO		26
M		585	PP		216
O		268	QQ		
P	53	69	RR	67	65
Q		254	SS		8
R			TT		80
T			UU	42	56
V			WW		
W		18	XX		443
X		10	YY		
Y			ZZ		
Z		102	AAA		
BB		8	BBB		23
DD			CCC		2

[a]Blanks indicate that the number of machines was not available or that VOC emissions could not be calculated.

TABLE A-6. EMISSIONS DATA FOR TREAD END CEMENTING[2,3,4,12-21,a]

Plant code	Calculated VOC emissions, metric tons/year	Plant code	Calculated VOC emissions, metric tons/year
A	7	EE	31
B		FF	21
C	22	GG	28
D	75	HH	
E	12	JJ	135
I	30	LL	22
K	40	NN	57
L		OO	36
M		PP	
O		QQ	
P	120	RR	33
Q	158	SS	210
R	18	TT	89
T		UU	167
V	10	WW	18
W	18	XX	46
X	29	YY	22
Y	52	ZZ	
Z		AAA	4
BB		BBB	31
DD		CCC	9

[a]Blank indicates that annual mass of VOC emissions could not be calculated.

TABLE A-7. EMISSIONS DATA FOR GREEN TIRE SPRAYING[2,3,4,12-21]

Plant code	Number of spray booths	Type of spray	Exit gas properties: Flow rate, m^3/s per booth, Average	Range	Temperature, °C	Gauge pressure, Pa	Calculated VOC emissions, metric tons/year
A	-[a]	Water-based	-[b]	-[a]	-[c]	0	-[b]
B	2	Organic-based	3.3	-[d]	27[e]	-[a]	30
C	2	Organic-based	2.4	1.5-3.3	-[c]	530	158
D	3	Organic-based	-[b]	-[a]	-[c]	0	439
E	-[a]	-[a]	-[b]	-[a]	-[a]	-[a]	-[b]
I	-[a]	Organic-based	-[b]	-[a]	-[a]	-[a]	116
K	4	Organic-based	3.0	2.6-3.3	-[c]	0	776
L	-[a]	Organic-based	-[b]	-[a]	-[c]	0	61
M	10	Organic-based	8.4	3.1-29.3	-[c]	-[a]	932
O	7	Organic-based	-[b]	-[a]	-[c]	-[a]	624
P	6	Organic-based	4.0	1.5-5.7	-[c]	530-2,000	512
Q	-[a]	Organic-based	-[b]	-[a]	-[a]	-[a]	502
R	7	Organic-based	3.1	1.5-4.1	-[c]	0	255
T	-[a]	-[a]	-[b]	-[a]	-[a]	-[a]	-[b]
V	8	Organic-based	3.5	-[d]	-[c]	-[a]	475
W	-[a]	-[a]	-[b]	-[a]	-[a]	-[a]	-[b]
X	5	Organic-based	0.9	-[d]	-[c]	0	157
Y	1	Organic-based	16.8	-[f]	-[c]	0	343
Z	2	Organic-based	3.7	1.7-5.7	-[c]	-[a]	675
BB	-[a]	Water-based	-[b]	-[a]	-[a]	-[a]	-[b]
DD	-[a]	Organic-based	-[b]	-[a]	-[a]	-[a]	-[b]
EE	8	Organic-based	3.8	1.3-6.0	-[c]	-[a]	433
FF	-[a]	Water-based	-[b]	-[a]	-[a]	-[a]	-[b]
GG	8	Organic-based	3.8	-[d]	-[c]	-[a]	457
HH	3	Organic-based	3.9	-[a]	21-29	0	78
JJ	4	Organic-based	7.0	3.8-11.3	-[c]	930-2,000	499
LL	13	Organic-based	1.7	1.0-2.8	-[c]	-[a]	157
NN	2	Organic-based	5.7	-[d]	-[c]	1,470	230
OO	4	Organic-based	3.0	2.4-3.3	21-38	-[a]	428
PP	-[a]	-[a]	-[b]	-[a]	-[a]	-[a]	-[b]
QQ	1	Organic-based	4.7	-[f]	-[c]	0	-[b]
RR	-[a]	Water-based	-[b]	-[a]	-[a]	-[a]	-[b]
SS	3	Water-based	3.7	3.6-3.8	13-24	-[a]	-[b]
TT	8	Organic-based	4.3	1.7-5.7	-[c]	-[a]	444
UU	-[a]	Water-based	-[b]	-[a]	-[a]	-[a]	-[b]
WW	9	Organic-based	5.2	3.2-9.4	21	0	864
XX	-[a]	-[a]	-[b]	-[a]	-[a]	-[a]	-[b]
YY	-[a]	Organic-based	-[b]	-[a]	-[a]	-[a]	76
ZZ	1	Organic-based	9.9	-[f]	-[c]	0	-[b]
AAA	-[a]	Organic-based	-[b]	-[a]	-[c]	-[a]	28
BBB	4	Organic-based	3.4	1.4-5.7	-[c]	-[a]	382
CCC	3	Organic-based	2.0	0.6-2.7	-[c]	0	180

[a] Not available.

[b] Not calculated.

[c] Ambient.

[d] All units have same exit gas flow rate.

[e] Maximum value.

[f] Only one value reported.

APPENDIX B

APPENDIX B. CALCULATIONS TO ESTIMATE VOC EMISSIONS FROM HEAT PROCESSING OF RUBBER

A temperature-weight loss correlation proposed by S. M. Rappaport[26] has been used to estimate emissions from curing. Emissions from other processes can be approximated using the ratio of the operating temperature to 180°C (the temperature at which curing emissions were measured) as a correction factor. In addition, Rappaport's numerical constants must be reduced by a factor of ten when estimating volatile organic compound emissions, because 90 percent of the weight losses that he observed could be attributed to evaporation of water.[27] The modified Rappaport equation is thus:

$$C = 1.27 \times 10^{-3} \ T$$

where C = weight loss, grams per kilogram

T = operating temperature, °C

In compounding, the mechanical release of heat normally raises the temperature of the rubber stock to 100°C. Twenty percent of the volatile species emitted can be assumed to be adsorbed on carbon black particulate that are simultaneously generated. The emission factor for compounding is therefore:

$$(0.8)\ (1.27 \times 10^{-3})\ (100) = 0.1 \text{ g/kg} \qquad (4)$$

A representative tire mass is required to convert the above emission factor to grams per tire. A passenger car tire was chosen for this purpose because it represents 80 percent of the total number of tires produced by the industry according to the information shown in Table 2-1. Data supplied by two Armstrong Rubber Company plants[2] that produce only passenger car tires were used to calculate an average tire mass of 11.4 kilograms. Using this value, the estimated emission factor for compounding is one gram per tire.

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16. ABSTRACT

This document provides the necessary guidance for development of regulations to limit emissions of volatile organic compounds (VOC) from manufacture of pneumatic rubber tire operations. Emissions are characterized and reasonably available control technology (RACT) is defined for each of four major sources: green tire spraying, undertread cementing, tread-end cementing, and bead dipping. Information on cost of control and environmental impact is also included.

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