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INTO

AP-42

Pages iii through vi (blank) replace same. New Contents.
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Pages 1.1-3 and 1.1-4 replace same. Editorial Changes.
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Revision.
Pages 11.2.6-1 through 11.2.6-6 (blank) replace pp. 11.2.6-1 through
11.2.6-4 (blank). Major Revision.



CONTENTS

	Page
INTRODUCTION	1
1. EXTERNAL COMBUSTION SOURCES	1.1-1
1.1 Bituminous Coal Combustion	1.1-1
1.2 Anthracite Coal Combustion	1.2-1
1.3 Fuel Oil Combustion	1.3-1
1.4 Natural Gas Combustion	1.4-1
1.5 Liquified Petroleum Gas Combustion	1.5-1
1.6 Wood Waste Combustion In Boilers	1.6-1
1.7 Lignite Combustion	1.7-1
1.8 Bagasse Combustion In Sugar Mills	1.8-1
1.9 Residential Fireplaces	1.9-1
1.10 Wood Stoves	1.10-1
1.11 Waste Oil Disposal	1.11-1
2. SOLID WASTE DISPOSAL	2.0-1
2.1 Refuse Incineration	2.1-1
2.2 Automobile Body Incineration	2.2-1
2.3 Conical Burners	2.3-1
2.4 Open Burning	2.4-1
2.5 Sewage Sludge Incineration	2.5-1
3. INTERNAL COMBUSTION ENGINE SOURCES	3-1
Glossary Of Terms	3-1
3.1 Highway Vehicles	3.1-1
3.2 Off Highway Mobile Sources	3.2-1
3.3 Off Highway Stationary Sources	3.3-1
4. EVAPORATION LOSS SOURCES	4.1-1
4.1 Dry Cleaning	4.1-1
4.2 Surface Coating	4.2-1
4.3 Storage Of Organic Liquids	4.3-1
4.4 Transportation And Marketing Of Petroleum Liquids	4.4-1
4.5 Cutback Asphalt, Emulsified Asphalt And Asphalt Cement ..	4.5-1
4.6 Solvent Degreasing	4.6-1
4.7 Waste Solvent Reclamation	4.7-1
4.8 Tank And Drum Cleaning	4.8-1
4.9 Graphic Arts	4.9-1
4.10 Commercial/Consumer Solvent Use	4.10-1
4.11 Textile Fabric Printing	4.11-1
5. CHEMICAL PROCESS INDUSTRY	5.1-1
5.1 Adipic Acid	5.1-1
5.2 Synthetic Ammonia	5.2-1
5.3 Carbon Black	5.3-1
5.4 Charcoal	5.4-1
5.5 Chlor-Alkali	5.5-1
5.6 Explosives	5.6-1
5.7 Hydrochloric Acid	5.7-1
5.8 Hydrofluoric Acid	5.8-1
5.9 Nitric Acid	5.9-1

	Page	
5.10	Paint And Varnish	5.10-1
5.11	Phosphoric Acid	5.11-1
5.12	Phthalic Anhydride	5.12-1
5.13	Plastics	5.13-1
5.14	Printing Ink	5.14-1
5.15	Soap And Detergents	5.15-1
5.16	Sodium Carbonate	5.16-1
5.17	Sulfuric Acid	5.17-1
5.18	Sulfur Recovery	5.18-1
5.19	Synthetic Fibers	5.19-1
5.20	Synthetic Rubber	5.20-1
5.21	Terephthalic Acid	5.21-1
5.22	Lead Alkyl	5.22-1
5.23	Pharmaceuticals Production	5.23-1
5.24	Maleic Anhydride	5.24-1
6.	FOOD AND AGRICULTURAL INDUSTRY	6.1-1
6.1	Alfalfa Dehydrating	6.1-1
6.2	Coffee Roasting	6.2-1
6.3	Cotton Ginning	6.3-1
6.4	Feed And Grain Mills And Elevators	6.4-1
6.5	Fermentation	6.5-1
6.6	Fish Processing	6.6-1
6.7	Meat Smokehouses	6.7-1
6.8	Ammonium Nitrate Fertilizers	6.8-1
6.9	Orchard Heaters	6.9-1
6.10	Phosphate Fertilizers	6.10-1
6.11	Starch Manufacturing	6.11-1
6.12	Sugar Cane Processing	6.12-1
6.13	Bread Baking	6.13-1
6.14	Urea	6.14-1
6.15	Beef Cattle Feedlots	6.15-1
6.16	Defoliation And Harvesting Of Cotton	6.16-1
6.17	Harvesting Of Grain	6.17-1
6.18	Ammonium Sulfate	6.18-1
7.	METALLURGICAL INDUSTRY	7.1-1
7.1	Primary Aluminum Production	7.1-1
7.2	Coke Production	7.2-1
7.3	Primary Copper Smelting	7.3-1
7.4	Ferroalloy Production	7.4-1
7.5	Iron And Steel Production	7.5-1
7.6	Primary Lead Smelting	7.6-1
7.7	Zinc Smelting	7.7-1
7.8	Secondary Aluminum Operations	7.8-1
7.9	Secondary Copper Smelting And Alloying	7.9-1
7.10	Gray Iron Foundries	7.10-1
7.11	Secondary Lead Smelting	7.11-1
7.12	Secondary Magnesium Smelting	7.12-1
7.13	Steel Foundries	7.13-1
7.14	Secondary Zinc Processing	7.14-1
7.15	Storage Battery Production	7.15-1

	Page	
7.16	Lead Oxide And Pigment Production	7.16-1
7.17	Miscellaneous Lead Products	7.17-1
7.18	Leadbearing Ore Crushing And Grinding	7.18-1
8.	MINERAL PRODUCTS INDUSTRY	8.1-1
8.1	Asphaltic Concrete Plants	8.1-1
8.2	Asphalt Roofing	8.2-1
8.3	Bricks And Related Clay Products	8.3-1
8.4	Calcium Carbide Manufacturing	8.4-1
8.5	Castable Refractories	8.5-1
8.6	Portland Cement Manufacturing	8.6-1
8.7	Ceramic Clay Manufacturing	8.7-1
8.8	Clay And Fly Ash Sintering	8.8-1
8.9	Coal Cleaning	8.9-1
8.10	Concrete Batching	8.10-1
8.11	Glass Fiber Manufacturing	8.11-1
8.12	Frit Manufacturing	8.12-1
8.13	Glass Manufacturing	8.13-1
8.14	Gypsum Manufacturing	8.14-1
8.15	Lime Manufacturing	8.15-1
8.16	Mineral Wool Manufacturing	8.16-1
8.17	Perlite Manufacturing	8.17-1
8.18	Phosphate Rock Processing	8.18-1
8.19	Construction Aggregate Processing	8.19-1
8.20	[Reserved]	8.20-1
8.21	Coal Conversion	8.21-1
8.22	Taconite Ore Processing	8.22-1
8.23	Metallic Minerals Processing	8.23-1
8.24	Western Surface Coal Mining	8.24-1
9.	PETROLEUM INDUSTRY	9.1-1
9.1	Petroleum Refining	9.1-1
9.2	Natural Gas Processing	9.2-1
10.	WOOD PRODUCTS INDUSTRY	10.1-1
10.1	Chemical Wood Pulping	10.1-1
10.2	Pulpboard	10.2-1
10.3	Plywood Veneer And Layout Operations	10.3-1
10.4	Woodworking Waste Collection Operations	10.4-1
11.	MISCELLANEOUS SOURCES	11.1-1
11.1	Forest Wildfires	11.1-1
11.2	Fugitive Dust Sources	11.2-1
11.3	Explosives Detonation	11.3-1
APPENDIX A	Miscellaneous Data And Conversion Factors	A-1
APPENDIX B	Emission Factors And New Source Performance Standards For Stationary Sources	B-1
APPENDIX C	NEDS Source Classification Codes And Emission Factor Listing	C-1
APPENDIX D	Projected Emission Factors For Highway Vehicles	D-1
APPENDIX E	Table Of Lead Emission Factors	E-1

PUBLICATIONS IN SERIES (CONT'D)

	Issuance	Release Date
Supplement 15		1/84
Section 3.3.4	Stationary Large Bore Diesel And Dual Fuel Engines	
Section 4.2.2.1	General Industrial Surface Coating	
Section 4.2.2.2	Can Coating	
Section 4.2.2.3	Magnet Wire Coating	
Section 4.2.2.4	Other Metal Coating	
Section 4.2.2.5	Flat Wood Interior Panel Coating	
Section 4.2.2.6	Paper Coating	
Section 4.2.2.7	Fabric Coating	
Section 4.8	Drum Burning	
Section 6.6	Fish Processing	
Section 6.8	Ammonium Nitrate	
Section 6.14	Urea	
Section 7.1	Primary Aluminum Production	
Section 7.3	Primary Copper Smelting	
Section 8.1	Asphaltic Concrete Plants	
Section 8.4	Calcium Carbide Manufacturing	
Section 11.2.2	Agricultural Tilling	
Update Package		9/85
Section 1.1	Bituminous And Subbituminous Coal Combustion	
Section 1.6	Wood Waste Combustion In Boilers	
Section 3.4	Stationary Large Bore Diesel And Dual Fuel Engines	
Section 4.2	Surface Coating	
Section 4.3	Storage Of Organic Liquids	
Section 4.4	Transportation And Marketing Of Petroleum Liquids	
Section 8.11	Glass Fiber Manufacturing	
Section 8.19	Construction Aggregate Processing	
Section 8.19.1	Sand And Gravel Processing	
Section 8.19.2	Crushed Stone Processing	
Section 8.20	(Reserved)	
Section 11.2.1	Unpaved Roads	
Section 11.2.5	Paved Urban Roads	
Section 11.2.6	Industrial Paved Roads	

-NOTICE-

This document is the final publication in the AP-42 series pursuant to the Third Edition (8/77).

All future AP-42 publications will be enumerated from the Fourth Edition (9/85).

PUBLICATIONS IN SERIES (CONT'D)

	Issuance	Release Date
	Supplement No. 13	8/82
Section 1.1	Bituminous and Subbituminous Coal Combustion	
Section 1.3	Fuel Oil Combustion	
Section 1.4	Natural Gas Combustion	
Section 1.5	Liquefied Petroleum Gas Combustion	
Section 1.6	Wood Waste Combustion In Boilers	
Section 1.7	Lignite Combustion	
Section 3.3.4	Stationary Large Bore Diesel and Dual Fuel Engines	
Section 4.2.2.8	Automobile and Light Duty Truck Surface Coating	
Section 4.2.2.9	Pressure Sensitive Tapes and Labels	
Section 4.2.2.10	Metal Coil Surface Coating	
Section 4.11	Textile Fabric Printing	
Section 5.16	Sodium Carbonate	
Section 5.20	Synthetic Rubber	
Section 7.15	Storage Battery Production	
Section 8.23	Metallic Minerals Processing	

	Supplement No. 14	5/83
Section 1.2	Anthracite Coal Combustion	
Section 1.6	Wood Waste Combustion In Boilers	
Section 1.9	Residential Fireplaces	
Section 1.10	Wood Stoves	
Section 2.4	Open Burning	
Section 4.2.2.11	Large Appliance Surface Coating	
Section 4.2.2.12	Metal Furniture Surface Coating	
Section 5.1	Adipic Acid	
Section 5.2	Synthetic Ammonia	
Section 5.3	Carbon Black	
Section 5.4	Charcoal	
Section 5.6	Explosives	
Section 5.10	Paint And Varnish	
Section 5.12	Phthalic Anhydride	
Section 5.14	Printing Ink	
Section 5.15	Soap And Detergents	
Section 5.21	Terephthalic Acid	
Section 5.24	Maleic Anhydride	
Section 7.1	Primary Aluminum Production	
Section 7.5	Iron And Steel Production	
Section 8.14	Gypsum Manufacturing	
Section 8.19	Construction Aggregate Processing	
Section 8.19.1	Sand And Gravel Processing	
Section 8.22	Taconite Ore Processing	
Section 8.24	Western Surface Coal Mining	
Section 11.2	Fugitive Dust Sources	
Section 11.2.1	Unpaved Roads	
Section 11.2.2	Agricultural Tilling	
Section 11.2.3	Aggregate Handling And Storage	
Section 11.2.6	Industrial Paved Roads	

load increases (especially as full load is approached) and with sudden load changes. Similarly, particulate can increase as the ash and fines contents increase. ("Fines" are defined in this context as coal particles smaller than one sixteenth inch, or about 1.6 millimeters, in diameter.) Conversely, particulate can be reduced significantly when overfire air pressures are increased.⁵

The primary kinds of particulate control devices used for coal combustion include multiple cyclones, electrostatic precipitators, fabric filters (baghouses) and scrubbers. Some measure of control will even result due to ash settling in boiler/air heater/economizer dust hoppers, large breeches and chimney bases. To the extent possible from the existing data base, the effects of such settling are reflected in the emission factors in Table 1.1-1.

Electrostatic precipitators (ESP) are the most common high efficiency control device used on pulverized coal and cyclone units, and they are being used increasingly on stokers. Generally, ESP collection efficiencies are a function of collection plate area per volumetric flow rate of flue gas through the device. Particulate control efficiencies of 99.9 weight percent are obtainable with ESPs. Fabric filters have recently seen increased use in both utility and industrial applications, generally effecting about 99.8 percent efficiency. An advantage of fabric filters is that they are unaffected by high flyash resistivities associated with low sulfur coals. ESPs located after air preheaters (i.e., cold side precipitators) may operate at significantly reduced efficiencies when low sulfur coal is fired. Scrubbers are also used to control particulate, although their primary use is to control sulfur oxides. One drawback of scrubbers is the high energy requirement to achieve control efficiencies comparable to those of ESPs and baghouses.²

Mechanical collectors, generally multiple cyclones, are the primary means of control on many stokers and are sometimes installed upstream of high efficiency control devices in order to reduce the ash collection burden. Depending on application and design, multiple cyclone efficiencies can vary tremendously. Where cyclone design flow rates are not attained (which is common with underfeed and overfeed stokers), these devices may be only marginally effective and may prove little better in reducing particulate than large breeching. Conversely, well designed multiple cyclones, operating at the required flow rates, can achieve collection efficiencies on spreader stokers and overfeed stokers of 90 to 95 percent. Even higher collection efficiencies are obtainable on spreader stokers with reinjected flyash because of the larger particle sizes and increased particulate loadings reaching the controls.⁵⁻⁶

Sulfur Oxides⁷⁻⁹ - Gaseous sulfur oxides from external coal combustion are largely sulfur dioxide (SO_2) and much lesser quantities of sulfur trioxide (SO_3) and gaseous sulfates. These compounds form as the organic and pyritic sulfur in the coal is oxidized during the combustion process. On average, 98 percent of the sulfur present in bituminous coal will be emitted as gaseous sulfur oxides, whereas somewhat less will be emitted when subbituminous coal is fired. The more alkaline nature of the ash in some subbituminous coals causes some of the sulfur to react to form various sulfate

TABLE 1.1-1. EMISSION FACTORS FOR EXTERNAL BITUMINOUS AND SUBBITUMINOUS COAL COMBUSTION^a

Firing Configuration	Particulate ^b		Sulfur Oxides ^c		Nitrogen Oxides ^d		Carbon Monoxide ^e		Nonmethane VOC ^{e,f}		Methane ^g	
	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton
Pulverized coal fired Dry bottom	5A	10A	19.5S(17.5S)	39S(35S)	10.5(7.5)8	21(15)8	0.3	0.6	0.04	0.07	0.015	0.03
Wet bottom	3.5A ^h	7A ^h	19.5S(17.5S)	39S(35S)	17	34	0.3	0.6	0.04	0.07	0.015	0.03
Cyclone furnace	1A ^h	2A ^h	19.5S(17.5S)	39S(35S)	18.5	37	0.3	0.6	0.04	0.07	0.015	0.03
Spreader stoker Uncontrolled	30J	60J	19.5S(17.5S)	39S(35S)	7	14	2.5	5	0.04	0.07	0.015	0.03
After multiple cyclone With fly ash reinjection from multiple cyclone	8.5	17	19.5S(17.5S)	39S(35S)	7	14	2.5	5	0.04	0.07	0.015	0.03
No fly ash reinjection from multiple cyclone	6	12	19.5S(17.5S)	39S(35S)	7	14	2.5	5	0.04	0.07	0.015	0.03
Overfeed stoker ^k Uncontrolled	8 ^m	16 ^m	19.5S(17.5S)	39S(35S)	3.25	7.5	3	6	0.04	0.07	0.015	0.03
After multiple cyclone	4.5 ⁿ	9 ⁿ	19.5S(17.5S)	39S(35S)	3.25	7.5	3	6	0.04	0.07	0.015	0.03
Underfeed stoker Uncontrolled	7.5P	15P	15.5S	31S	4.75	9.5	5.5	11	0.65	1.3	0.4	0.8
After multiple cyclone	5.5 ⁿ	11 ⁿ	15.5S	31S	4.75	9.5	5.5	11	0.65	1.3	0.4	0.8
Handfired units	7.5	15	15.5S	31S	1.5	3	45	90	5	10	4	8

^aFactors represent uncontrolled emissions unless otherwise specified and should be applied to coal consumption as fired.

^bBased on EPA Method 5 (front half catch) as described in Reference 12. Where particulate is expressed in terms of coal ash content, A, factor is determined by multiplying weight % ash content of coal (as fired) by the numerical value preceding the "A". For example, if coal having 8% ash is fired in a dry bottom unit, the particulate emission factor would be 5 x 8, or 40 kg/Mg (80 lb/ton). The "condensable" matter collected in back half catch of EPA Method 5 averages 5% of front half, or "filterable", catch for pulverized coal and cyclone furnaces; 10% for spreader stokers; 15% for other stokers; and 50% for handfired units (References 6, 19, 49).

^cExpressed as SO₂, including SO₂, SO₃, and gaseous sulfates. Factors in parentheses should be used to estimate gaseous SO₂ emissions for subbituminous coal. In all cases, "S" is weight % sulfur content of coal as fired. See Footnote b for example calculation. On average for bituminous coal, 97% of fuel sulfur is emitted as SO₂, and only about 0.7% of fuel sulfur is emitted as SO₃ and gaseous sulfate. An equally small percent of fuel sulfur is emitted as particulate sulfate (References 9, 13). Small quantities of sulfur are also retained in bottom ash. With subbituminous coal generally about 10% more fuel sulfur is retained in the bottom ash and particulate because of the more alkaline nature of the coal ash. Conversion to gaseous sulfate appears about the same as for bituminous coal.

^dExpressed as NO₂. Generally, 95 - 99 volume % of nitrogen oxides present in combustion exhaust will be in the form of NO, the rest NO₂ (Reference 11). To express factors as NO, multiply by factor of 0.66. All factors represent emission at baseline operation (i.e., 60 - 110% load and no NO_x control measures, as discussed in text).

^eNominal values achievable under normal operating conditions. Values one or two orders of magnitude higher can occur when combustion is not complete.

^fNonmethane volatile organic compounds (VOC), expressed as C₂ to C₁₆ n-alkane equivalents (Reference 58). Because of limited data on NMVOC available to distinguish the effects of firing configuration, all data were averaged collectively to develop a single average for pulverized coal units, cyclones, spreaders and overfeed stokers.

^gParenthetical value is for tangentially fired boilers.

^hUncontrolled particulate emissions, when no fly ash reinjection is employed. When control device is installed, and collected fly ash is reinjected to boiler, particulate from boiler reaching control equipment can increase by up to a factor of two.

ⁱAccounts for fly ash settling in an economizer, air heater or breeching upstream of control device or stack. (Particulate directly at boiler outlet typically will be twice this level.) Factor should be applied even when fly ash is reinjected to boiler from boiler, air heater or economizer dust hoppers.

^jIncludes travelling grate, vibrating grate and chain grate stokers.

^kAccounts for fly ash settling in breeching or stack base. Particulate loadings directly at boiler outlet typically can be 50% higher.

^lSee text for discussion of apparently low multiple cyclone control efficiencies, regarding uncontrolled emissions.

^mAccounts for fly ash settling in breeching downstream of boiler outlet.

TABLE 1.6-1. EMISSION FACTORS FOR WOOD AND BARK COMBUSTION IN BOILERS

Pollutant/Fuel Type/Control	kg/Mg	lb/ton	Emission Factor Rating
Particulate ^{a,b}			
Bark ^c			
Multiclone, with fly ash reinjection ^d	7	14	B
Multiclone, without fly ash reinjection ^d	4.5	9	B
Uncontrolled	24	47	B
Wood/bark mixture ^e			
Multiclone, with fly ash reinjection ^f	3	6	C
Multiclone, without fly ash reinjection ^f	2.7	5.3	C
Uncontrolled ^g	3.6	7.2	C
Wood ^h			
Uncontrolled	4.4	8.8	C
Sulfur Dioxide ^j	0.075 (0.01 - 0.2)	0.15 (0.02 - 0.4)	B
Nitrogen Oxides (as NO ₂) ^k			
50,000 - 400,000 lb steam/hr	1.4	2.8	B
<50,000 lb steam/hr	0.34	0.68	B
Carbon Monoxide ^m	2 - 24	4 - 47	C
VOC			
Nonmethane ⁿ	0.7	1.4	D
Methane ^p	0.15	0.3	E

^aReferences 2, 4, 9, 17-18. For boilers burning gas or oil as an auxiliary fuel, all particulates are assumed to result from only wood waste fuel.

^bMay include condensible hydrocarbons consisting of pitches and tars, mostly from back half catch of EPA Method 5. Tests reported in Reference 20 indicate that condensible hydrocarbons account for 4% of total particulate weight.

^cBased on fuel moisture content of about 50%.

^dAfter control equipment, assuming an average collection efficiency of 80%. Data from References 4, 7-8 indicate that 50% fly ash reinjection increases the dust load at the cyclone inlet 1.2 to 1.5 times, while 100% fly ash reinjection increases the load 1.5 to 2 times without reinjection.

^eBased on fuel moisture content of 33%.

^fBased on large dutch ovens and spreader stokers (averaging 23,430 kg steam/hr) with steam pressures from 20 - 75 kpa (140 - 530 psi).

^gBased on small dutch ovens and spreader stokers (usually operating <9075 kg steam/hr), with pressures from 5 - 30 kpa (35 - 230 psi). Careful air adjustments and improved fuel separation and firing were used on some units, but the effects cannot be isolated.

^hReferences 12-13, 19, 27. Wood waste includes cuttings, shavings, sawdust and chips, but not bark. Moisture content ranges from 3 - 50 weight %. Based on small units (<3000 kg steam/hr) in New York and North Carolina.

^jReference 23. Based on tests of fuel sulfur content and sulfur dioxide emissions at four mills burning bark. The lower limit of the range (in parentheses) should be used for wood, and higher values for bark. A heating value of 5000 kcal/kg (9000 BTU/lb) is assumed. The factors are based on the dry weight of fuel.

^kReferences 7, 24-26. Several factors can influence emission rates, including combustion zone temperatures, excess air, boiler operating conditions, fuel moisture and fuel nitrogen content. Factors on a dry weight basis.

^mReference 30. Factors on a dry weight basis.

ⁿReferences 20, 30. Nonmethane VOC reportedly consists of compounds with a high vapor pressure such as alpha pinene.

^pReference 30. Based on an approximation of methane/non-methane ratio, which is very variable. Methane, expressed as a % of total volatile organic compounds, varied from 0 - 74 weight %.

a tenfold increase in the dust loadings of some systems, although increases of 1.2 to 2 times are more typical for boilers using 50 to 100 percent reinjection. A major factor affecting this dust loading increase is the extent to which the sand and other noncombustibles can successfully be separated from the flyash before reinjection to the furnace.

Although reinjection increases boiler efficiency from 1 to 4 percent and minimizes the emissions of uncombusted carbon, it also increases boiler maintenance requirements, decreases average flyash particle size and makes collection more difficult. Properly designed reinjection systems should separate sand and char from the exhaust gases, to reinject the larger carbon particles to the furnace and to divert the fine sand particles to the ash disposal system.

Several factors can influence emissions, such as boiler size and type, design features, age, load factors, wood species and operating procedures. In addition, wood is often cofired with other fuels. The effect of these factors on emissions is difficult to quantify. It is best to refer to the references for further information.

The use of multitube cyclone mechanical collectors provides the particulate control for many hogged boilers. Usually, two multicyclones are used in series, allowing the first collector to remove the bulk of the dust and the second collector to remove smaller particles. The collection efficiency for this arrangement is from 65 to 95 percent. Low pressure drop scrubbers and fabric filters have been used extensively for many years. On the West Coast, pulse jets have been used.

Emission factors for wood waste boilers are presented in Table 1.6-1.

References for Section 1.6

1. Steam, 38th Edition, Babcock and Wilcox, New York, NY, 1972.
2. Atmospheric Emissions from the Pulp and Paper Manufacturing Industry, EPA-450/1-73-002, U.S. Environmental Protection Agency, Research Triangle Park, NC, September 1973.
3. C-E Bark Burning Boilers, C-E Industrial Boiler Operations, Combustion Engineering, Inc., Windsor, CT, 1973.
4. A. Barron, Jr., "Studies on the Collection of Bark Char throughout the Industry", Journal of the Technical Association of the Pulp and Paper Industry, 53(8):1441-1448, August 1970.
5. H. Kreisinger, "Combustion of Wood Waste Fuels", Mechanical Engineering, 61:115-120, February 1939.

3.4 STATIONARY LARGE BORE DIESEL AND DUAL FUEL ENGINES

3.4.1 General

The primary domestic use of large bore diesel engines, i.e., those greater than 560 cubic inch displacement per cylinder (CID/CYL), is in oil and gas exploration and production. These engines, in groups of three to five, supply mechanical power to operate drilling (rotary table), mud pumping and hoisting equipment, and may also operate pumps or auxiliary power generators. Another frequent application of large bore diesels is electricity generation for both base and standby service. Smaller uses include irrigation, hoisting and nuclear power plant emergency cooling water pump operation.

Dual fuel engines were developed to obtain compression ignition performance and the economy of natural gas, using a minimum of 5 to 6 percent diesel fuel to ignite the natural gas. Dual fuel large bore engines (greater than 560 CID/CYL) have been used almost exclusively for prime electric power generation.

3.4.2 Emissions and Controls

The primary pollutant of concern from large bore diesel and dual fuel engines is NO_x , which readily forms in the high temperature, pressure and excess air environment found in these engines. Lesser amounts of carbon monoxide and hydrocarbons are also emitted. Sulfur dioxide emissions will usually be quite low because of the negligible sulfur content of diesel fuels and natural gas.

The major variables affecting NO_x emissions from diesel engines are injection timing, manifold air temperature, engine speed, engine load and ambient humidity. In general, NO_x emissions decrease with increasing humidity.

Because NO_x is the primary pollutant from diesel and dual fuel engines, control measures to date have been directed mainly at limiting NO_x emissions. The most effective NO_x control technique for diesel engines is fuel injection retard, achieving reductions (at eight degrees of retard) of up to 40 percent. Additional NO_x reductions are possible with combined retard and air/fuel ratio change. Both retarded fuel injection (8°) and air/fuel ratio change of five percent are also effective in reducing NO_x emissions from dual fuel engines, achieving nominal NO_x reductions of about 40 percent and maximum NO_x reductions of up to 70 percent.

Other NO_x control techniques exist but are not considered feasible because of excessive fuel penalties, capital cost, or maintenance or operational problems. These techniques include exhaust gas recirculation (EGR), combustion chamber modification, water injection and catalytic reduction.

TABLE 3.4-1. EMISSION FACTORS FOR STATIONARY LARGE BORE DIESEL AND DUAL FUEL ENGINES^a

EMISSION FACTOR RATING: C

Engine type	Particulate ^b	Nitrogen oxides ^c	Carbon monoxide	VOC ^d		Sulfur dioxide ^e
				Methane	Nonmethane	
Diesel						
lb/10 ³ hph	2.4	24	6.4	0.07	0.63	2.8
g/hph	1.1	11	2.9	0.03	0.29	1.3
g/kWh	1.5	15	3.9	0.04	0.4	1.7
lb/10 ³ gal ^f	50	500	130	1	13	60
g/l	6	60	16	0.2	1.6	7.2
Dual fuel						
lb/10 ³ hph	NA	18	5.9	4.7	1.5	0.70
g/hph	NA	8	2.7	2.1	0.7	0.32
g/kWh	NA	11	3.6	2.9	0.9	0.43

^aRepresentative uncontrolled levels for each fuel, determined by weighting data from several manufacturers. Weighting based on % of total horsepower sold by each manufacturer during a five year period. NA = not available.

^bEmission Factor Rating: E. Approximation based on test of a medium bore diesel. Emissions are minimum expected for engine operating at 50 - 100% full rated load. At 0% load, emissions would increase to 30 g/l. Reference 2.

^cMeasured as NO₂. Factors are for engines operated at rated load and speed.

^dNonmethane VOC is 90% of total VOC from diesel engines but only 25% of total VOC emissions from dual fuel engines. Individual chemical species within the non-methane fraction are not identified. Molecular weight of nonmethane gas stream is assumed to be that of methane.

^eBased on assumed sulfur content of 0.4 weight % for diesel fuel and 0.46 g/scm (0.20 gr/scf) for pipeline quality natural gas. Dual fuel SO₂ emissions based on 5% oil/95% gas mix. Emissions should be adjusted for other fuel ratios.

^fThese factors calculated from the above factors, assuming heating values of 40 MJ/l (145,000 Btu/gal) for oil and 41 MJ/scm (1100 Btu/scf) for natural gas, and an average fuel consumption of 9.9 MJ/kWh (7000 Btu/hph).

References for Section 3.4

1. Standards Support And Environmental Impact Statement, Volume I: Stationary Internal Combustion Engines, EPA-450/2-78-125a, U. S. Environmental Protection Agency, Research Triangle Park, NC, July 1979.
2. Telephone communication between William H. Lamason, Office Of Air Quality Planning And Standards, U. S. Environmental Protection Agency, Research Triangle Park, NC, and John H. Wasser, Office Of Research And Development, U. S. Environmental Protection Agency, Research Triangle Park, NC, July 15, 1983.

4.2 SURFACE COATING

Surface coating operations involve the application of paint, varnish, lacquer or paint primer, for decorative or protective purposes. This is accomplished by brushing, rollings, spraying, flow coating and dipping operations. Some industrial surface coating operations include automobile assembly, job enameling, and manufacturing of aircraft, containers, furniture, appliances and plastic products. Nonindustrial applications of surface coatings include automobile refinishing and architectural coating of domestic, industrial, government and institutional structures, including building interiors and exteriors and exteriors and signs and highway markings. Nonindustrial Surface Coating is discussed below in Section 4.2.1, and Industrial Surface Coating in Section 4.2.2.

Emissions of volatile organic compounds (VOC) occur in surface coating operations because of evaporation of the paint vehicle, thinner or solvent used to facilitate the application of coatings. The major factor affecting these emissions is the amount of volatile matter contained in the coating. The volatile portion of most common surface coatings averages about 50 percent, and most, if not all, of this is emitted during the application of coatings. The major factor affecting these emissions is the amount of volatile matter contained in the coating. The volatile portion of most common surface coatings averages about 50 percent, and most, if not all, of this is emitted during the application and drying of the coating. The compounds released include aliphatic and aromatic hydrocarbons, alcohols, ketones, esters, alkyl and aryl hydrocarbon solvents, and mineral spirits. Table 4.2-1 presents emission factors for general surface coating operations.

TABLE 4.2-1. EMISSION FACTORS FOR GENERAL SURFACE COATING APPLICATIONS^a

EMISSION FACTOR RATING: B

Coating Type	Emissions ^b	
	kg/Mg	lb/ton
Paint	560	1120
Varnish and Shellac	500	1000
Lacquer	770	1540
Enamel	420	840
Primer (zinc chromate)	660	1320

^aReference 1.

^bReference 2. Nonmethane VOC.

References for Section 4.2

1. Products Finishing, 41(6A):4-54, March 1977.
2. Air Pollution Engineering Manual, Second Edition, AP-40, U. S. Environmental Protection Agency, Research Triangle Park, NC, May 1973. Out of Print.



4.3 STORAGE OF ORGANIC LIQUIDS

4.3.1 Process Description

Storage vessels containing organic liquids can be found in many industries, including (1) petroleum producing and refining, (2) petrochemical and chemical manufacturing, (3) bulk storage and transfer operations, and (4) other industries consuming or producing organic liquids. Organic liquids in the petroleum industry, usually called petroleum liquids, generally are mixtures of hydrocarbons having dissimilar true vapor pressures (for example, gasoline and crude oil). Organic liquids in the chemical industry, usually called volatile organic liquids, are composed of pure chemicals or mixtures of chemicals with similar true vapor pressures (for example, benzene or a mixture of isopropyl and butyl alcohols).

Five basic tank designs are used for organic liquid storage vessels, fixed roof, external floating roof, internal floating roof, variable vapor space, and pressure (low and high).

Fixed Roof Tanks - A typical fixed roof tank is shown in Figure 4.3-1. This type of tank consists of a cylindrical steel shell with a permanently affixed roof, which may vary in design from cone or dome shaped to flat.

Fixed roof tanks are commonly equipped with a pressure/vacuum vent that allows them to operate at a slight internal pressure or vacuum to prevent the release of vapors during very small changes in temperature, pressure or liquid level. Of current tank designs, the fixed roof tank is the least expensive to construct and is generally considered the minimum acceptable equipment for storage of organic liquids.

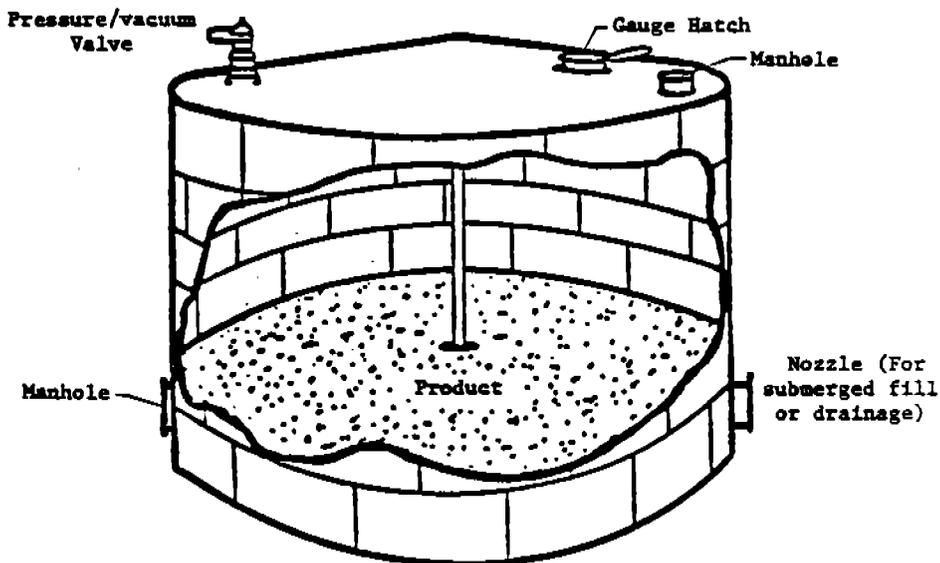


Figure 4.3-1. Typical fixed roof tank.¹

External Floating Roof Tanks - A typical external floating roof tank is shown in Figure 4.3-2. This type of tank consists of a cylindrical steel shell equipped with a roof which floats on the surface of the stored liquid, rising and falling with the liquid level. The liquid surface is completely covered by the floating roof, except at the small annular space between the roof and the tank wall. A seal (or seal system) attached to the roof contacts the tank wall (with small gaps, in some cases) and covers the annular space. The seal slides against the tank wall as the roof is raised or lowered. The purpose of the floating roof and the seal (or seal system) is to reduce the evaporation loss of the stored liquid.

Internal Floating Roof Tanks - An internal floating roof tank has both a permanent fixed roof and a deck inside. The deck rises and falls with the liquid level and either floats directly on the liquid surface (contact deck) or rests on pontoons several inches above the liquid surface (non-contact deck). The terms "deck" and "floating roof" can be used interchangeably in reference to the structure floating on the liquid inside the tank. There are two basic types of internal floating roof tanks, tanks in which the fixed roof is supported by vertical columns within the tank, and tanks with a self-supporting fixed roof and no internal support columns. Fixed roof tanks that have been retrofitted to employ a floating deck are typically of the first type, while external floating roof tanks typically have a self-supporting roof when converted to an internal floating roof tank. Tanks initially constructed with both a fixed roof and a floating deck may be of either type.

The deck serves to restrict evaporation of the organic liquid stock. Evaporation losses from decks may come from deck fittings, nonwelded deck seams, and the annular space between the deck and tank wall. Typical contact deck and noncontact deck internal floating roof tanks are shown in

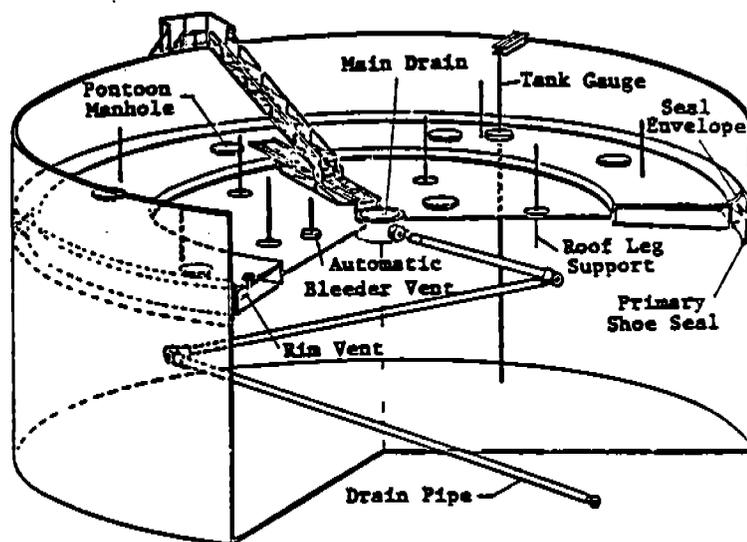


Figure 4.3-2. External floating roof tank.¹

Figure 4.3-3. Contact decks can be aluminum sandwich panels with a honeycomb aluminum core floating in contact with the liquid, or pan steel decks floating in contact with the liquid, with or without pontoons. Typical noncontact decks have an aluminum deck or an aluminum grid framework supported above the liquid surface by tubular aluminum pontoons or other bouyant structures. Both types of deck incorporate rim seals, which slide against the tank wall as the deck moves up and down. In addition, these tanks are freely vented by circulation vents at the top of the fixed roof. The vents minimize the possibility of organic vapor accumulation in concentrations approaching the flammable range. An internal floating roof tank not freely vented is considered a pressure tank.

Pressure Tanks - There are two classes of pressure tanks in general use, low pressure (2.5 to 15 psig) and high pressure (higher than 15 psig). Pressure tanks generally are used for storage of organic liquids and gases with high vapor pressures and are found in many sizes and shapes, depending on the operating pressure of the tank. Pressure tanks are equipped with a pressure/vacuum vent that is set to prevent venting loss from boiling and breathing loss from daily temperature or barometric pressure changes. High pressure storage tanks can be operated so that virtually no evaporative or working losses occur. In low pressure tanks, working losses can occur with atmospheric venting of the tank during filling operations.

Variable Vapor Space Tanks - Variable vapor space tanks are equipped with expandable vapor reservoirs to accomodate vapor volume fluctuations attributable to temperature and barometric pressure changes. Although variable vapor space tanks are sometimes used independently, they are normally connected to the vapor spaces of one or more fixed roof tanks. The two most common types of variable vapor space tanks are lifter roof tanks and flexible diaphragm tanks.

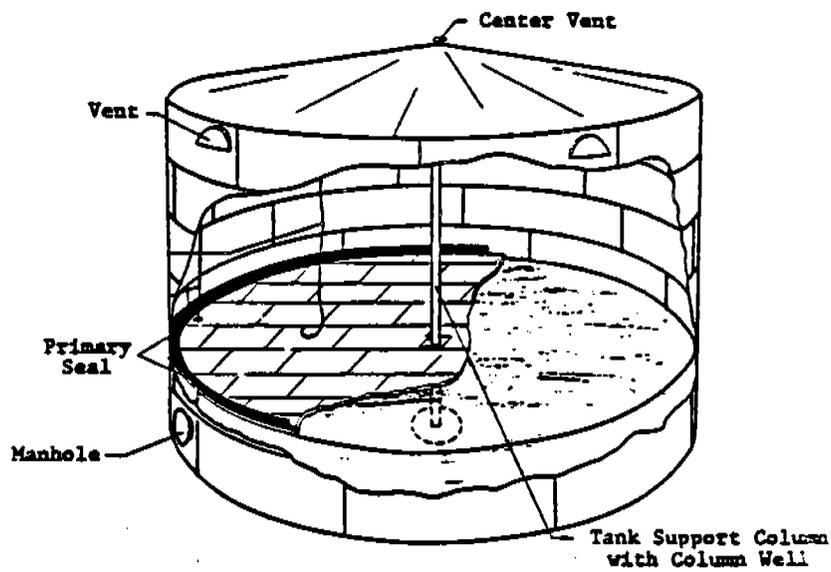
Lifter roof tanks have a telescoping roof that fits loosely around the outside of the main tank wall. The space between the roof and the wall is closed by either a wet seal, which is a trough filled with liquid, or a dry seal, which uses a flexible coated fabric.

Flexible diaphragm tanks use flexible membranes to provide expandable volume. They may be either separate gasholder units or integral units mounted atop fixed roof tanks.

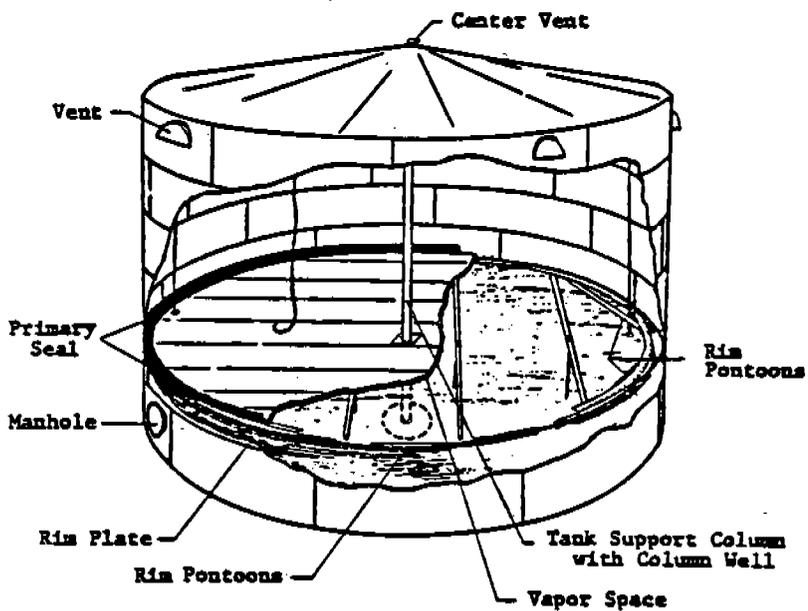
4.3.2 Emissions And Controls

Emission sources from organic liquids in storage depend upon the tank type. Fixed roof tank emission sources are breathing loss and working loss. External or internal floating roof tank emission sources are standing storage loss and withdrawal loss. Standing storage loss includes rim seal loss, deck fitting loss and deck seam loss. Pressure tanks and variable vapor space tanks are also emission sources.

Fixed Roof Tanks - Two significant types of emissions from fixed roof tanks are breathing loss and working loss. Breathing loss is the expulsion of vapor from a tank through vapor expansion and contraction, which are the results of changes in temperature and barometric pressure. This loss occurs without any liquid level change in the tank.



Contact Deck Type



Noncontact Deck Type

Figure 4.3-3. Internal floating roof tanks.¹

The combined loss from filling and emptying is called working loss. Filling loss comes with an increase of the liquid level in the tank, when the pressure inside the tank exceeds the relief pressure and vapors are expelled from the tank. Emptying loss occurs when air drawn into the tank during liquid removal becomes saturated with organic vapor and expands, thus exceeding the capacity of the vapor space.

The following equations, provided to estimate emissions, are applicable to tanks with vertical cylindrical shells and fixed roofs. These tanks must be substantially liquid and vapor tight and must operate approximately at atmospheric pressure. Fixed roof tank breathing losses can be estimated from²:

$$L_B = 2.26 \times 10^{-2} M_V \left(\frac{P}{P_A - P} \right)^{0.68} D^{1.73} H^{0.51} \Delta T^{0.50} F_P C K_C \quad (1)$$

where:

L_B = fixed roof breathing loss (lb/yr)

M_V = molecular weight of vapor in storage tank (lb/lb mole), see Note 1

P_A = average atmospheric pressure at tank location (psia)

P = true vapor pressure at bulk liquid conditions (psia), see Note 2

D = tank diameter (ft)

H = average vapor space height, including roof volume correction (ft), see Note 3

ΔT = average ambient diurnal temperature change (°F)

F_P = paint factor (dimensionless), see Table 4.3-1

C = adjustment factor for small diameter tanks (dimensionless), see Figure 4.3-4

K_C = product factor (dimensionless), see Note 4

Notes: (1) The molecular weight of the vapor, M_V , can be determined by Table 4.3-2 for selected petroleum liquids and volatile organic liquids or by analysis of vapor samples. Where mixtures of organic liquids are stored in a tank, M_V can be estimated from the liquid composition. As an example of the latter calculation, consider a liquid known to be composed of components A and B with mole fractions in the liquid X_a and X_b , respectively. Given the vapor pressures of the pure

TABLE 4.3-1. PAINT FACTORS FOR FIXED ROOF TANKS^a

Tank color		Paint factors (F_p)	
		Paint condition	
Roof	Shell	Good	Poor
White	White	1.00	1.15
Aluminum (specular)	White	1.04	1.18
White	Aluminum (specular)	1.16	1.24
Aluminum (specular)	Aluminum (specular)	1.20	1.29
White	Aluminum (diffuse)	1.30	1.38
Aluminum (diffuse)	Aluminum (diffuse)	1.39	1.46
White	Gray	1.30	1.38
Light gray	Light gray	1.33	1.44 ^b
Medium gray	Medium gray	1.40	1.58 ^b

^aReference 2.

^bEstimated from the ratios of the seven preceding paint factors.

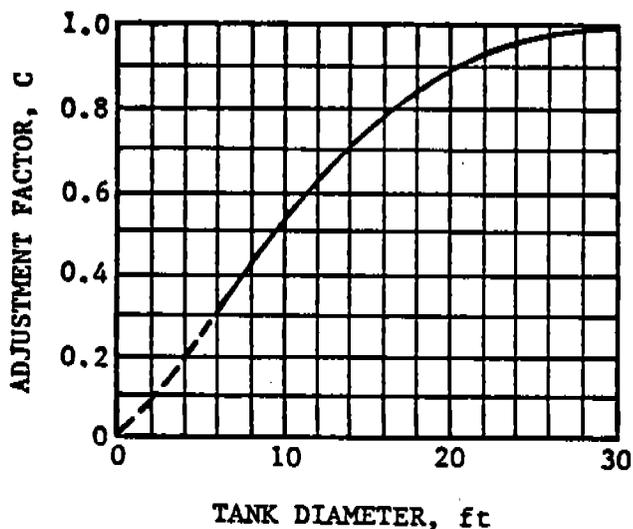


Figure 4.3-4. Adjustment factor (C) for small diameter tanks.²

TABLE 4.3-2. PHYSICAL PROPERTIES OF TYPICAL ORGANIC LIQUIDS^a

Organic liquid ^b	Vapor molecular weight @ 60°F	Product density (d), lb/gal @ 60°F	Condensed vapor density (w), lb/gal @ 60°F	True vapor pressure in psia at:						
				40°F	50°F	60°F	70°F	80°F	90°F	100°F
Petroleum Liquids^c										
Gasoline RVP 13	62	5.6	4.9	4.7	5.7	6.9	8.3	9.9	11.7	13.8
Gasoline RVP 10	66	5.6	5.1	3.4	4.2	5.2	6.2	7.4	8.8	10.5
Gasoline RVP 7	68	5.6	5.2	2.3	2.9	3.5	4.3	5.2	6.2	7.4
Crude oil RVP 5	50	7.1	4.5	1.8	2.3	2.8	3.4	4.0	4.8	5.7
Jet naphtha (JP-4)	80	6.4	5.4	0.8	1.0	1.3	1.6	1.9	2.4	2.7
Jet kerosene	130	7.0	6.1	0.0041	0.0060	0.0085	0.011	0.015	0.021	0.029
Distillate fuel no. 2	130	7.1	6.1	0.0031	0.0045	0.0074	0.0090	0.012	0.016	0.022
Residual oil no. 6	190	7.9	6.4	0.00002	0.00003	0.00004	0.00006	0.00009	0.00013	0.00019
Volatile Organic Liquids										
Acetone	58	6.6	6.6	1.7	2.2	2.9	3.7	4.7	5.9	7.3
Acrylonitrile	53	6.8	6.8	0.8	1.0	1.4	1.8	2.4	3.1	4.0
Benzene	78	7.4	7.4	0.6	0.9	1.2	1.5	2.0	2.6	3.3
Carbon disulfide	76	10.6	10.6	3.0	3.9	4.8	6.0	7.4	9.2	11.2
Carbon tetrachloride	154	13.4	13.4	0.8	1.1	1.4	1.8	2.3	3.0	3.8
Chloroform	119	12.5	12.5	1.5	1.9	2.5	3.2	4.1	5.2	6.3
Cyclohexane	84	6.5	6.5	0.7	0.9	1.2	1.6	2.1	2.6	3.2
1,2-Dichloroethane	99	10.5	10.5	0.6	0.8	1.0	1.4	1.7	2.2	2.8
Ethylacetate	88	7.6	7.6	0.6	0.8	1.1	1.5	1.9	2.5	3.2
Ethyl alcohol	46	6.6	6.6	0.2	0.4	0.6	0.9	1.2	1.7	2.3
Isopropyl alcohol	60	6.6	6.6	0.2	0.3	0.6	0.7	0.9	1.3	1.8
Methyl alcohol	32	6.6	6.6	0.7	1.0	1.4	2.0	2.6	3.5	4.5
Methylene chloride	85	11.1	11.1	3.1	4.3	5.4	6.8	8.7	10.3	13.3
Methylethyl ketone	72	6.7	6.7	0.7	0.9	1.2	1.5	2.1	2.7	3.3
Methylmethacrylate	100	7.9	7.9	0.1	0.2	0.3	0.6	0.8	1.1	1.4
1,1,1-Trichloroethane	133	11.2	11.2	0.9	1.2	1.6	2.0	2.6	3.3	4.2
Trichloroethylene	131	12.3	12.3	0.5	0.7	0.9	1.2	1.5	2.0	2.0
Toluene	92	7.3	7.3	0.2	0.2	0.3	0.4	0.6	0.8	1.0
Vinylacetate	86	7.8	7.8	0.7	1.0	1.3	1.7	2.3	3.1	4.0

^aReferences 3-4.^bFor a more comprehensive listing of volatile organic liquids, see Reference 3.^cRVP = Reid vapor pressure in psia.

components, P_a and P_b , and the molecular weights of the pure components, M_a^a and M_b^b , M_V is calculated:

$$M_V = M_a \left(\frac{P_a X_a}{P_t} \right) + M_b \left(\frac{P_b X_b}{P_t} \right)$$

where: P_t , by Raoult's law, is:

$$P_t = P_a X_a + P_b X_b$$

- (2) True vapor pressures for organic liquids can be determined from Figures 4.3-5 or 4.3-6, or Table 4.3-2. In order to use Figures 4.3-5 or 4.3-6, the stored liquid temperature, T_S , must be determined in degrees Fahrenheit. T_S is determined from Table 4.3-3, given the average annual ambient temperature, T_A , in degrees Fahrenheit. True vapor pressure is the equilibrium partial pressure exerted by a volatile organic liquid, as defined by ASTM-D-2879 or as obtained from standard reference texts. Reid vapor pressure is the absolute vapor pressure of volatile crude oil and volatile nonviscous petroleum liquids, except liquified petroleum gases, as determined by ASTM-D-323.
- (3) The vapor space in a cone roof is equal in volume to a cylinder, which has the same base diameter as the cone and is one third the height of the cone. If information is not available, assume H equals one half tank height.
- (4) For crude oil, $K_C = 0.65$. For all other organic liquids, $K_C = 1.0$.

Fixed roof tank working losses can be estimated from²:

$$L_W = 2.40 \times 10^{-5} M_V P V N K_N K_C \quad (2)$$

where:

L_W = fixed roof working loss (lb/year)

M_V = molecular weight of vapor in storage tank (lb/lb mole), see Note 1 to Equation 1

P = true vapor pressure at bulk liquid temperature (psia), see Note 2 to Equation 1

V = tank capacity (gal)

N = number of turnovers per year (dimensionless)

$$N = \frac{\text{Total throughput per year (gal)}}{\text{Tank capacity, } V \text{ (gal)}}$$

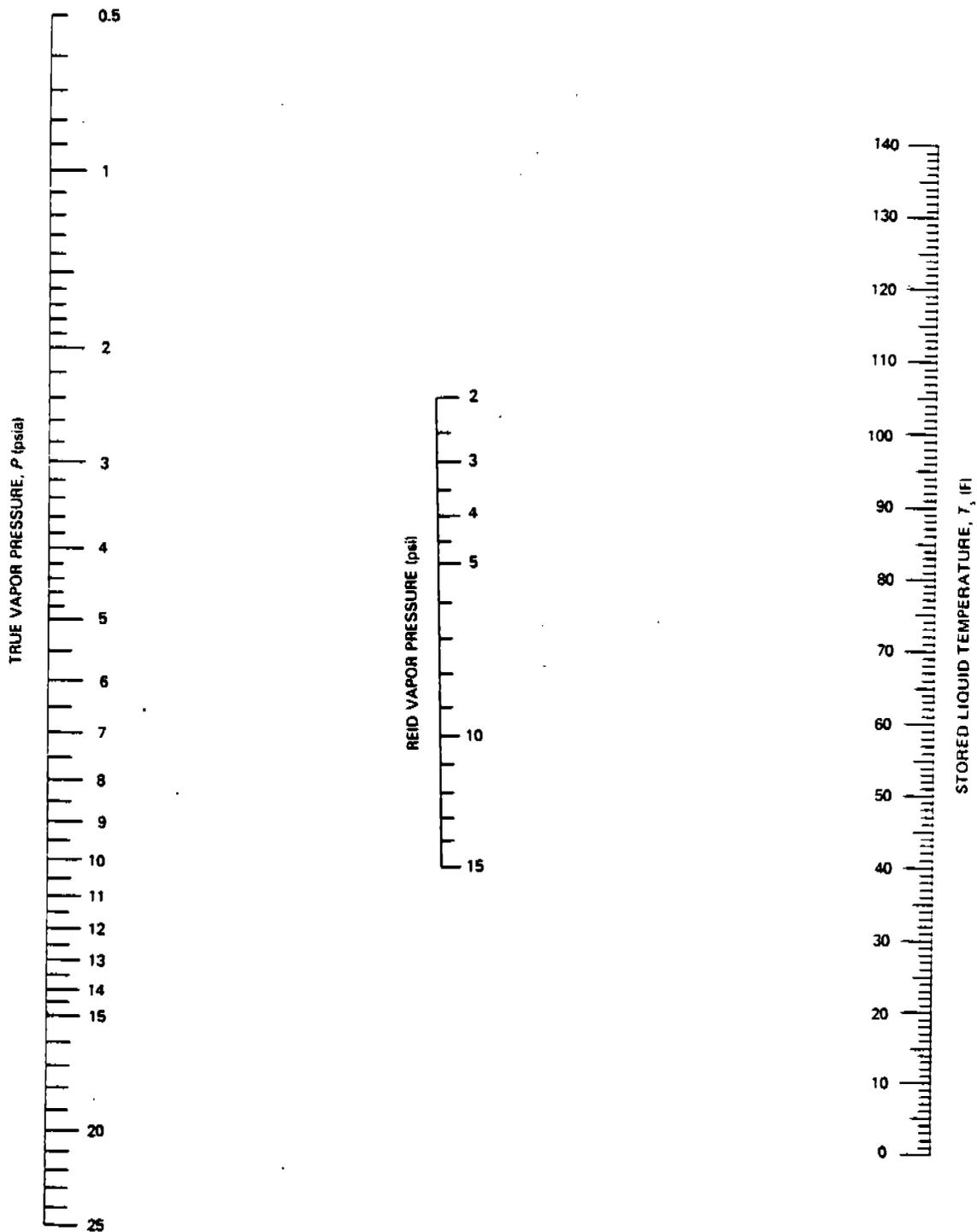
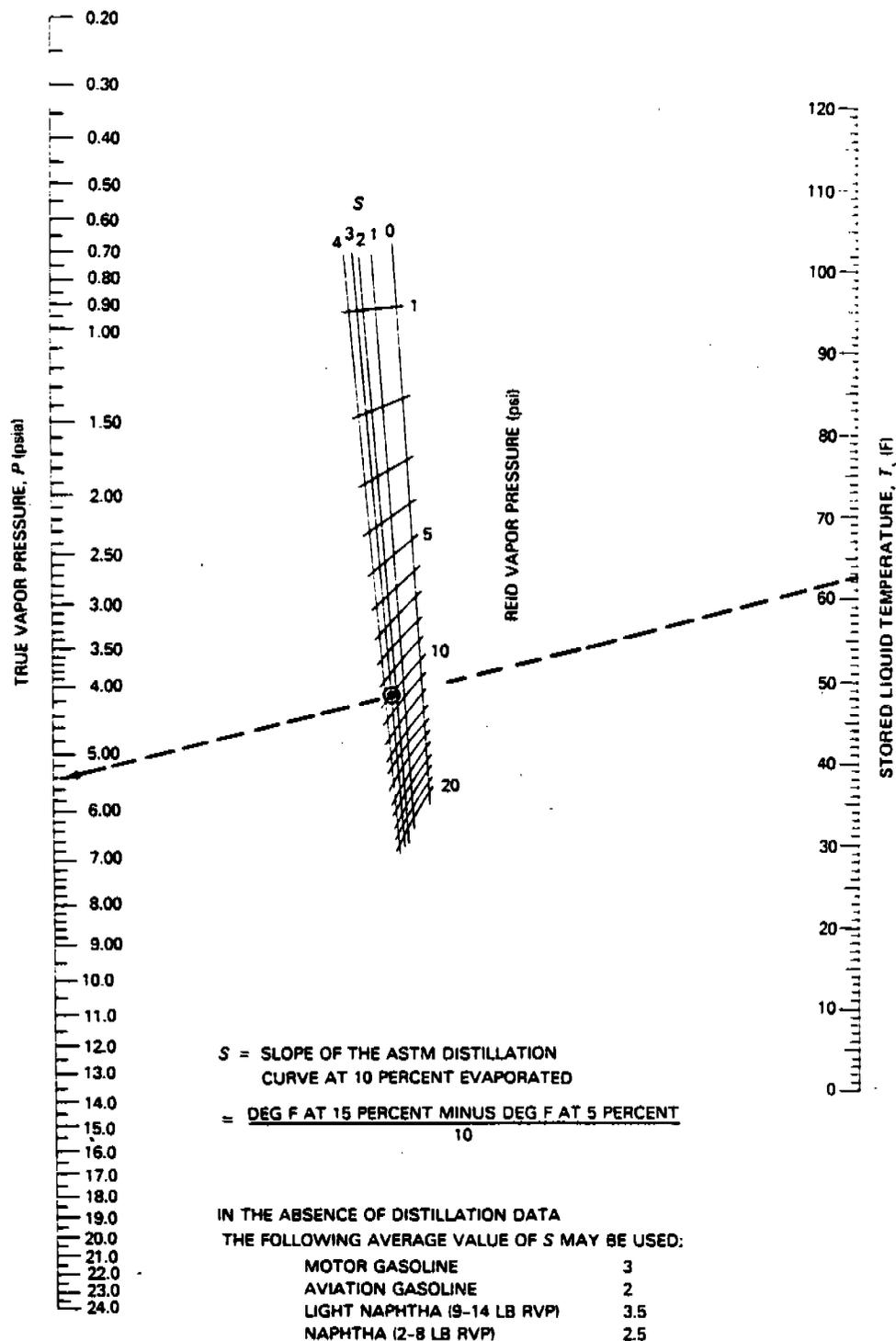


Figure 4.3-5. True vapor pressure (P) of crude oils (2-15 psi RVP).⁶



NOTE: Dashed line illustrates sample problem for RVP = 10 pounds per square inch, gasoline ($S = 3$), and $T_s = 62.5$ F.
 SOURCE: Nomograph drawn from the data of the National Bureau of Standards.

Figure 4.3-6. True vapor pressure (P) of refined petroleum liquids like gasoline and naphthas (1-20 psi RVP).⁶

K_N = turnover factor (dimensionless), see Figure 4.3-7

K_C = product factor (dimensionless), see Note 1

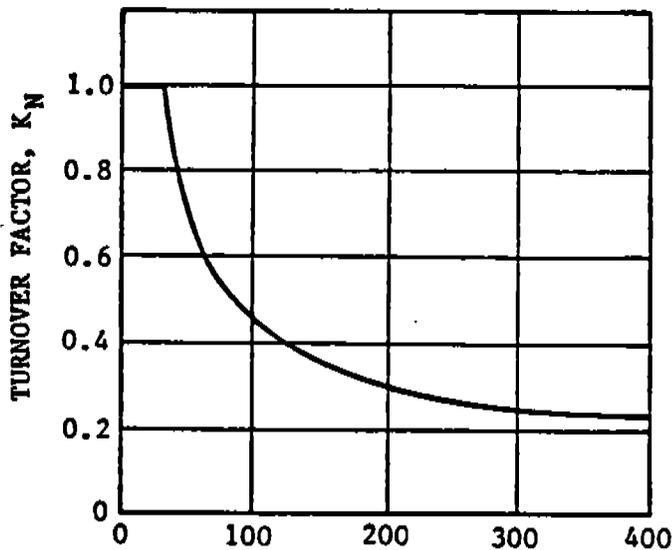
Note: (1) For crude oil, $K_C = 0.84$. For all other organic liquids, $K_C = 1.0$.

TABLE 4.3-3. AVERAGE STORAGE TEMPERATURE (T_S) AS A FUNCTION OF TANK PAINT COLOR^a

Tank color	Average storage temperature, T_S
White	$T_A^b + 0$
Aluminum	$T_A + 2.5$
Gray	$T_A + 3.5$
Black	$T_A + 5.0$

^aReference 5.

^b T_A is the average annual ambient temperature in degrees Fahrenheit.



$$\text{TURNOVERS PER YEAR} = \frac{\text{ANNUAL THROUGHPUT}}{\text{TANK CAPACITY}}$$

Note: For 36 turnovers per year or less, $K_N = 1.0$

Figure 4.3-7. Turnover factor (K_N) for fixed roof tanks.

Several methods are used to control emissions from fixed roof tanks. Emissions from fixed roof tanks can be controlled by the installation of an internal floating roof and seals to minimize evaporation of the product being stored. The control efficiency of this method ranges from 60 to 99 percent, depending on the type of roof and seals installed and on the type of organic liquid stored.

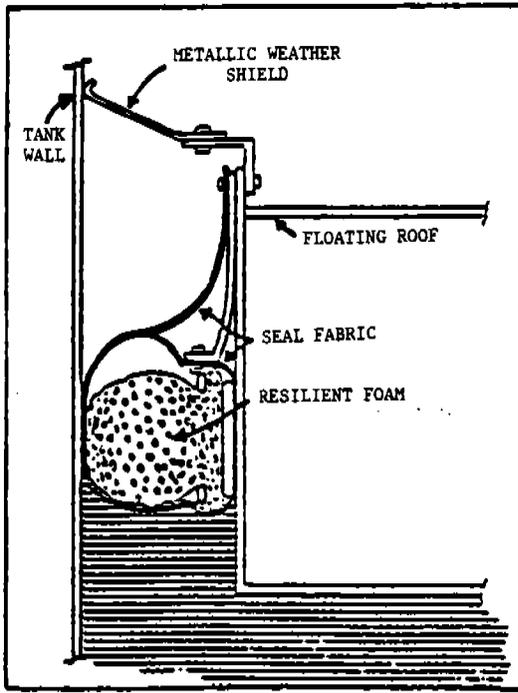
The vapor recovery system collects emissions from storage vessels and converts them to liquid product. Several vapor recovery procedures may be used, including vapor/liquid absorption, vapor compression, vapor cooling, vapor/solid adsorption, or a combination of these. The overall control efficiencies of vapor recovery systems are as high as 90 to 98 percent, depending on the method used, the design of the unit, the composition of vapors recovered, and the mechanical condition of the system.

Another method of emission control on fixed roof tanks is thermal oxidation. In a typical thermal oxidation system, the air/vapor mixture is injected through a burner manifold into the combustion area of an incinerator. Control efficiencies for this system can range from 96 to 99 percent.

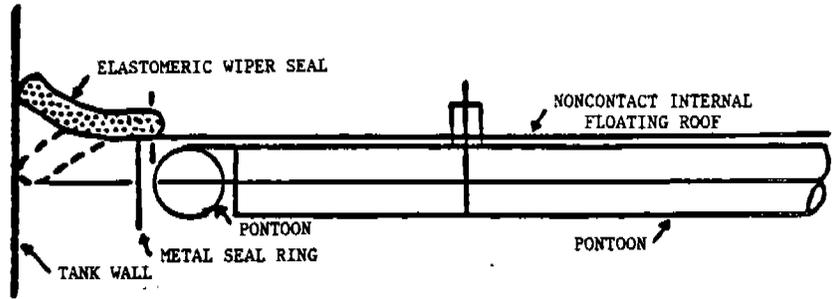
External And Internal Floating Roof Tanks - Total emissions from floating roof tanks are the sum of standing storage losses and withdrawal losses. Standing storage loss from internal floating roof tanks includes rim seal, deck fitting, and deck seam losses. Standing storage loss from external floating roof tanks, as discussed here, includes only rim seal loss, since deck fitting loss equations have not been developed. There is no deck seam loss, because the decks have welded sections.

Standing storage loss from external floating roof tanks, the major element of evaporative loss, results from wind induced mechanisms as air flows across the top of an external floating roof tank. These mechanisms may vary, depending upon the type of seals used to close the annular vapor space between the floating roof and the tank wall. Standing storage emissions from external floating roof tanks are controlled by one or two separate seals. The first seal is called the primary seal, and the other, mounted above the primary seal, is called the secondary seal. There are three basic types of primary seals used on external floating roofs, mechanical (metallic shoe), resilient (nonmetallic), and flexible wiper. The resilient seal can be mounted to eliminate the vapor space between the seal and liquid surface (liquid mounted), or to allow a vapor space between the seal and liquid surface (vapor mounted). A primary seal serves as a vapor conservation device by closing the annular space between the edge of the floating roof and the tank wall. Some primary seals are protected by a metallic weather shield. Additional evaporative loss may be controlled by a secondary seal. Secondary seals can be either flexible wiper seals or resilient filled seals. Two configurations of secondary seal are currently available, shoe mounted and rim mounted. Although there are other seal system designs, the systems described here compose the majority in use today. See Figure 4.3-8 for examples of primary and secondary seal configurations.

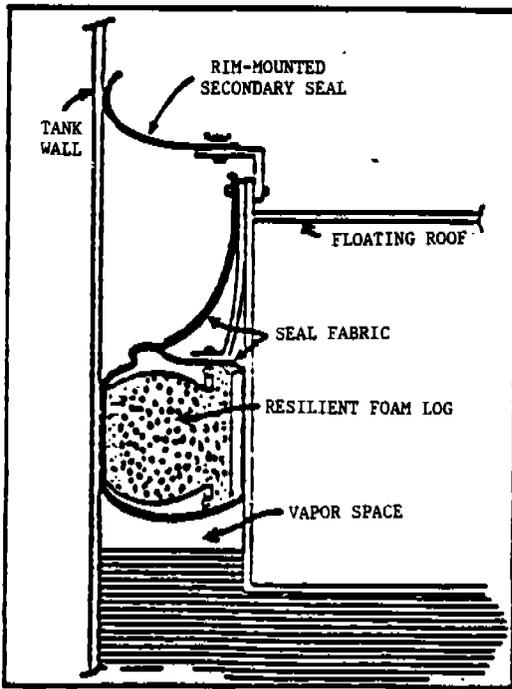
Typical internal floating roofs generally incorporate two types of primary seals, resilient foam filled seals and wipers. Similar in design



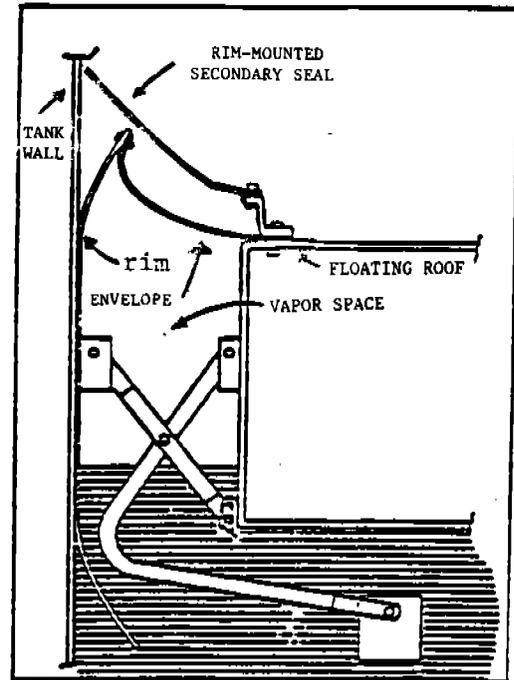
a. Liquid mounted seal with weather shield.



b. Elastomeric wiper seal.



c. Vapor mounted seal with rim mounted secondary seal.



d. Metallic shoe seal with shoe mounted secondary seal.

Figure 4.3-8. Primary and secondary seal configurations.¹

to those in external floating roof tanks, these seals close the annular vapor space between the edge of the floating roof and the tank wall. Secondary seals are not commonly used with internal floating roof tanks.

Deck fitting loss emissions from internal floating roof tanks result from penetrations in the roof by deck fittings, fixed roof column supports or other openings. There are no procedures for estimating emissions from external roof tank deck fittings. The most common fittings with relevance to controllable vapor losses are described as follows:¹

1. Access Hatch. An access hatch is an opening in the deck with a peripheral vertical well that is large enough to provide passage of workers and materials through the deck for construction or servicing. Attached to the opening is a removable cover which may be bolted and/or gasketed to reduce evaporative loss. On noncontact decks, the well should extend down into the liquid to seal off the vapor space below the deck.

2. Automatic Gauge Float Well. A gauge float is used to indicate the level of liquid within the tank. The float rests on the liquid surface, inside a well that is closed by a cover. The cover may be bolted and/or gasketed to reduce evaporation loss. As with other similar deck penetrations, the well extends fixed into the liquid on noncontact decks.

3. Column Well. For fixed roofs that are column-supported, the columns pass through deck openings with peripheral vertical wells. On noncontact decks, the well should extend down into the liquid. The wells are equipped with closure devices to reduce evaporative loss and may be gasketed or ungasketed to further reduce the loss. Closure devices are typically sliding covers or flexible fabric sleeve seals.

4. Ladder Well. Some tanks are equipped with internal ladders that extend from a manhole in the fixed roof to the tank bottom. The deck opening through which the ladder passes has a peripheral vertical well. On noncontact decks, the well should extend down into the liquid. The wells are typically covered with a gasketed or ungasketed sliding cover.

5. Roof Leg or Hanger Well. To prevent damage to fittings underneath the deck and to allow for tank cleaning or repair, supports are provided to hold the deck a predetermined distance off the tank bottom. These supports consist of adjustable or fixed legs attached to the floating deck or hangers suspended from the fixed roof. For adjustable legs or hangers, the load-carrying element passes through a well or sleeve into the deck. With noncontact decks, the well should extend into the liquid.

6. Sample Pipe or Well. A funnel-shaped sample well may be provided to allow for sampling of the liquid with a sample thief. A closure is typically located at the lower end of the funnel and frequently consists of a horizontal piece of fabric slit radially to allow thief entry. The well should extend into the liquid on noncontact decks. Alternatively, a sample well may consist of a slotted pipe extending into the liquid, equipped with a gasketed or ungasketed sliding cover.

7. Vacuum Breaker. A vacuum breaker equalizes the pressure of the vapor space across the deck as the deck is either being landed on or floated off its legs. The vacuum breaker consists of a well with a cover. Attached to the underside of the cover is a guided leg of such length that it contacts the tank bottom as the internal floating deck approaches. When in contact with the tank bottom, the guided leg mechanically opens the breaker by lifting the cover off the well; otherwise, the cover closes the well. The closure may be gasketed or ungasketed. Because the purpose of the vacuum breaker is to allow the free exchange of air and/or vapor, the well does not extend appreciably below the deck.

The decks of internal floating roofs typically are made by joining several sections of deck material, resulting in seams in the deck. To the extent that these seams are not completely vapor tight, they become a source of emissions. It should be noted that external floating roof tanks and welded internal floating roofs do not have deck seam losses.

Withdrawal loss is another source of emissions from floating roof tanks. This loss is the vaporization of liquid that clings to the tank wall and is exposed to the atmosphere when a floating roof is lowered by withdrawal of liquid. There is also clingage of liquid to columns in internal floating roof tanks which have a column supported fixed roof.

Total Losses From Floating Roof Tanks - Total floating roof tank emissions are the sum of rim seal, withdrawal, deck fitting, and deck seam losses. It should be noted that external floating roof tanks and welded internal floating roofs do not have deck seam losses. Also, there are no procedures for estimating emissions from external floating roof tank deck fittings. The equations provided in this Section are applicable only to freely vented internal floating roof tanks or external floating roof tanks. The equations are not intended to be used in the following applications: to estimate losses from closed internal floating roof tanks (tanks vented only through a pressure-vacuum vent); to estimate losses from unstabilized or boiling stocks or from mixtures of hydrocarbons or petrochemicals for which the vapor pressure is not known or cannot be readily predicted; or to estimate losses from tanks in which the materials used in the seal system and/or deck construction are either deteriorated or significantly permeated by the stored liquid.⁶ Total losses may be written as:

$$L_T = L_R + L_W + L_F + L_D \quad (3)$$

where:

L_T = total loss (lb/yr)

L_R = rim seal loss (see Equation 4)

L_W = withdrawal loss (see Equation 5)

L_F = deck fitting loss (see Equation 6)

L_D = deck seam loss (see Equation 7)

Rim Seal Loss - Rim seal loss from floating roof tanks can be estimated by the following equation⁵⁻⁶:

$$L_R = K_S V^n P^* D M_V K_C \quad (4)$$

where:

L_R = rim seal loss (lb/yr)

K_S = seal factor (lb-mole/(ft (mi/hr)ⁿ yr)), see Table 4.3-4

V = average wind speed at tank site (mi/hr), see Note 1

n = seal related wind speed exponent (dimensionless), see Table 4.3-4

P^* = vapor pressure function (dimensionless), see Note 2

$$P^* = \frac{P}{P_A} \left[1 + \left(1 - \frac{P}{P_A} \right)^{0.5} \right]^2$$

where:

P = true vapor pressure at average actual liquid storage temperature (psia), see Note 2 to Equation 1

P_A = average atmospheric pressure at tank location (psia)

D = tank diameter (ft)

M_V = average vapor molecular weight (lb/lb-mole), see Note 1 to Equation 1

K_C = product factor (dimensionless), see Note 3

Notes: (1) If the wind speed at the tank site is not available, wind speed data from the nearest local weather station may be used as an approximation.

(2) P^* can be calculated or read directly from Figure 4.3-9.

(3) For all organic liquids except crude oil, $K_C = 1.0$. For crude oil, $K_C = 0.4$.

Withdrawal Loss - The withdrawal loss from floating roof storage tanks can be estimated using Equation 5.⁵⁻⁶

$$L_W = \frac{(0.943)QCW_L}{D} \left[1 + \left(\frac{N_C F_C}{D} \right) \right] \quad (5)$$

TABLE 4.3-4. SEAL RELATED FACTORS FOR FLOATING ROOF TANKS^a

Tank and seal type	Welded Tank		Riveted Tank	
	K _S	n	K _S	n
External floating roof tanks ^b				
Metallic shoe seal				
Primary seal only	1.2	1.5	1.3	1.5
With shoe mounted secondary seal	0.8	1.2	1.4	1.2
With rim mounted secondary seal	0.2	1.0	0.2	1.6
Liquid mounted resilient seal				
Primary seal only	1.1	1.0	NA ^c	NA
With weather shield	0.8	0.9	NA	NA
With rim mounted secondary seal	0.7	0.4	NA	NA
Vapor mounted resilient seal				
Primary seal only	1.2	2.3	NA	NA
With weather shield	0.9	2.2	NA	NA
With rim mounted secondary seal	0.2	2.6	NA	NA
Internal floating roof tanks ^d				
Liquid mounted resilient seal				
Primary seal only	3.0	0	NA	NA
With rim mounted secondary seal ^e	1.6	0	NA	NA
Vapor mounted resilient seal				
Primary seal only	6.7	0	NA	NA
With rim mounted secondary seal ^e	2.5	0	NA	NA

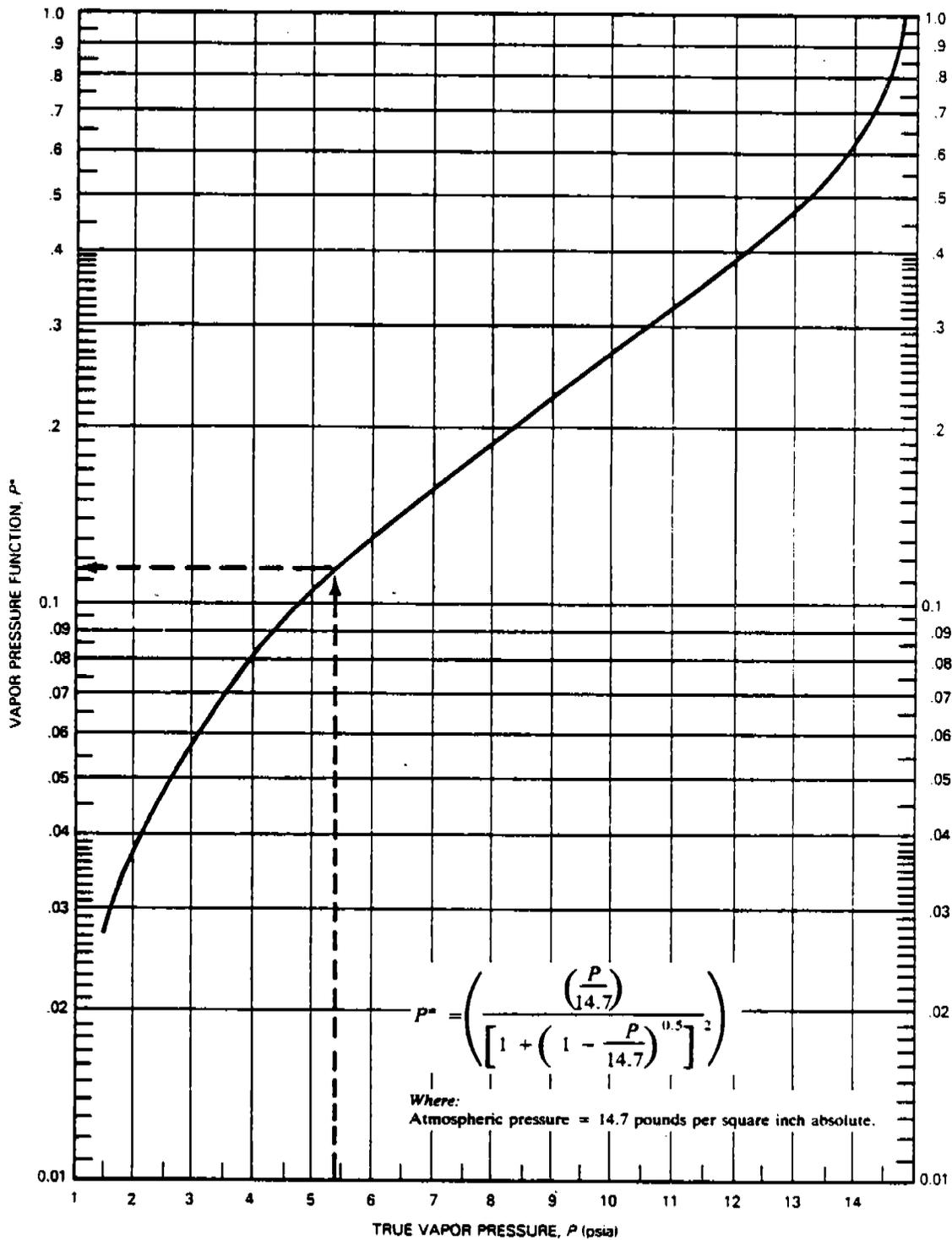
^aBased on emissions from tank seal systems in reasonably good working condition, no visible holes, tears, or unusually large gaps between the seals and the tank wall. The applicability of K_S decreases in cases where the actual gaps exceed the gaps assumed during development of the correlation.

^bReference 5.

^cNA = Not Applicable.

^dReference 6.

^eIf tank specific information is not available about the secondary seal on an internal floating roof tank, then assume only a primary seal is present.



NOTE: Dashed line illustrates sample problem for $P = 5.4$ pounds per square inch absolute.

Figure 4.3-9. Vapor pressure function (P^*).⁵

where:

L_W = withdrawal loss (lb/yr)

Q = throughput (bbl/year) (tank capacity [bbl] times annual turnover rate)

C = shell clingage factor (bbl/1,000 ft²), see Table 4.3-5

W_L = average organic liquid density (lb/gal), see Note 1

D = tank diameter (ft)

N_C = number of columns (dimensionless), see Note 3

F_C = effective column diameter (ft) [column perimeter (ft)/ π], see Note 4

- Notes: (1) If W_L is not known, an average value of 5.6 lb/gallon can be assumed for gasoline. An average value cannot be assumed for crude oil, since densities are highly variable.
- (2) The constant, 0.943, has dimensions of (1,000 ft³ x gal/bbl²).
- (3) For self-supporting fixed roof or an external floating roof tank:

$$N_C = 0.$$

For column supported fixed roof:

N_C = use tank specific information, or see Table 4.3-6.

- (4) Use tank specific effective column diameter; or

F_C = 1.1 for 9 inch by 7 inch builtup columns,
0.7 for 8 inch diameter pipe columns, and
1.0 if column construction details are not known.

Deck Fitting Loss - Deck fitting loss estimation procedures for external floating roof tanks are not available. Therefore, the following procedure applies only to internal floating roof tanks.

Fitting losses from internal floating roof tanks can be estimated by the following equation⁶:

$$L_F = F_F P^* M_V K_C \quad (6)$$

TABLE 4.3-5. AVERAGE CLINGAGE FACTORS (C) (bbl/1,000 ft²)^a

Liquid	Shell condition		
	Light rust ^b	Dense rust	Gunite lined
Gasoline	0.0015	0.0075	0.15
Single component stocks	0.0015	0.0075	0.15
Crude oil	0.0060	0.030	0.60

^aReference 5.

^bIf no specific information is available, these values can be assumed to represent the most common condition of tanks currently in use.

TABLE 4.3-6. TYPICAL NUMBER OF COLUMNS AS A FUNCTION OF TANK DIAMETER FOR INTERNAL FLOATING ROOF TANKS WITH COLUMN SUPPORTED FIXED ROOFS^a

Tank diameter range D (ft)	Typical number of columns, N _C
0 < D ≤ 85	1
85 < D ≤ 100	6
100 < D ≤ 120	7
120 < D ≤ 135	8
135 < D ≤ 150	9
150 < D ≤ 170	16
170 < D ≤ 190	19
190 < D ≤ 220	22
220 < D ≤ 235	31
235 < D ≤ 270	37
270 < D ≤ 275	43
275 < D ≤ 290	49
290 < D ≤ 330	61
330 < D ≤ 360	71
360 < D ≤ 400	81

^aReference 1. This table was derived from a survey of users and manufacturers. The actual number of columns in a particular tank may vary greatly with age, fixed roof style, loading specifications, and manufacturing prerogatives. Data in this table should not supersede information on actual tanks.

where:

L_F = the fitting loss in pounds per year

F_F = total deck fitting loss factor (lb-mole/yr)

$$= [(N_{F_1} K_{F_1}) + N_{F_2} K_{F_2}) + \dots + (N_{F_n} K_{F_n})]$$

where:

N_{F_i} = number of deck fittings of a particular type
($i = 0, 1, 2, \dots, n$) (dimensionless)

K_{F_i} = deck fitting loss factor for a particular type fitting
($i = 0, 1, 2, \dots, n$) (lb-mole/yr)

n = total number of different types of fittings
(dimensionless)

P^* , M_V , K_C = as defined for Equation 4

The value of F_F may be calculated by using actual tank specific data for the number of each fitting type (N_{F_i}) and then multiplying by the fitting loss factor for each fitting (K_{F_i}).¹ Values of fitting loss factors and typical number of fittings are presented in Table 4.3-7. Where tank specific data for the number and kind of deck fittings are unavailable, then F_F can be approximated according to tank diameter. Figures 4.3-10 and 4.3-11 present F_F plotted against tank diameter for column supported fixed roofs and self-supporting fixed roofs, respectively.

Deck Seam Loss - Deck seam loss applies only to internal floating roof tanks with bolted decks. External floating roofs have welded decks and, therefore, no deck seam loss. Deck seam loss can be estimated by the following equation:⁶

$$L_D = K_D S_D D^2 P^* M_V K_C \quad (7)$$

where

L_D = deck seam losses (lb/yr)

K_D = deck seam loss per unit seam length factor (lb-mole/ft yr)

= 0.0 for welded deck and external floating roof tanks,
0.34 for bolted deck

S_D = deck seam length factor (ft/ft²)

$$= \frac{L_{\text{seam}}}{A_{\text{deck}}}$$

TABLE 4.3-7. SUMMARY OF INTERNAL FLOATING DECK FITTING LOSS FACTORS (K_F) AND TYPICAL NUMBER OF FITTINGS (N_F)^a

Deck fitting type	Deck fitting loss factor, K_F (lb-mole/yr)	Typical number of fittings, N_F
Access hatch		1
Bolted cover, gasketed	1.6	
Unbolted cover, gasketed	11 ^b	
Unbolted cover, ungasketed	25 ^b	
Automatic gauge float well		1
Bolted cover, gasketed	5.1	
Unbolted cover, gasketed	15 ^b	
Unbolted cover, ungasketed	28 ^b	
Column well		(see Table 4.3-6)
Builtup column-sliding cover, gasketed	33 ^b	
Builtup column-sliding cover, ungasketed	47 ^b	
Pipe column-flexible fabric sleeve seal	10	
Pipe column-sliding cover, gasketed	19	
Pipe column-sliding cover, ungasketed	32	
Ladder well		1
Sliding cover, gasketed	56 ^b	
Sliding cover, ungasketed	76 ^b	
Roof leg or hanger well		$(5 + \frac{D}{10} + \frac{D^2}{600})^c$
Adjustable	7.9 ^b	
Fixed	0	
Sample pipe or well		1
Slotted pipe-sliding cover, gasketed	44	
Slotted pipe-sliding cover, ungasketed	57 ^b	
Sample well-slit fabric seal, 10% open area	12 ^b	
Stub drain, 1 inch diameter ^d	1.2	$(\frac{D^2}{125})^c$
Vacuum breaker		1
Weighted mechanical actuation, gasketed	0.7 ^b	
Weighted mechanical actuation, ungasketed	0.9	

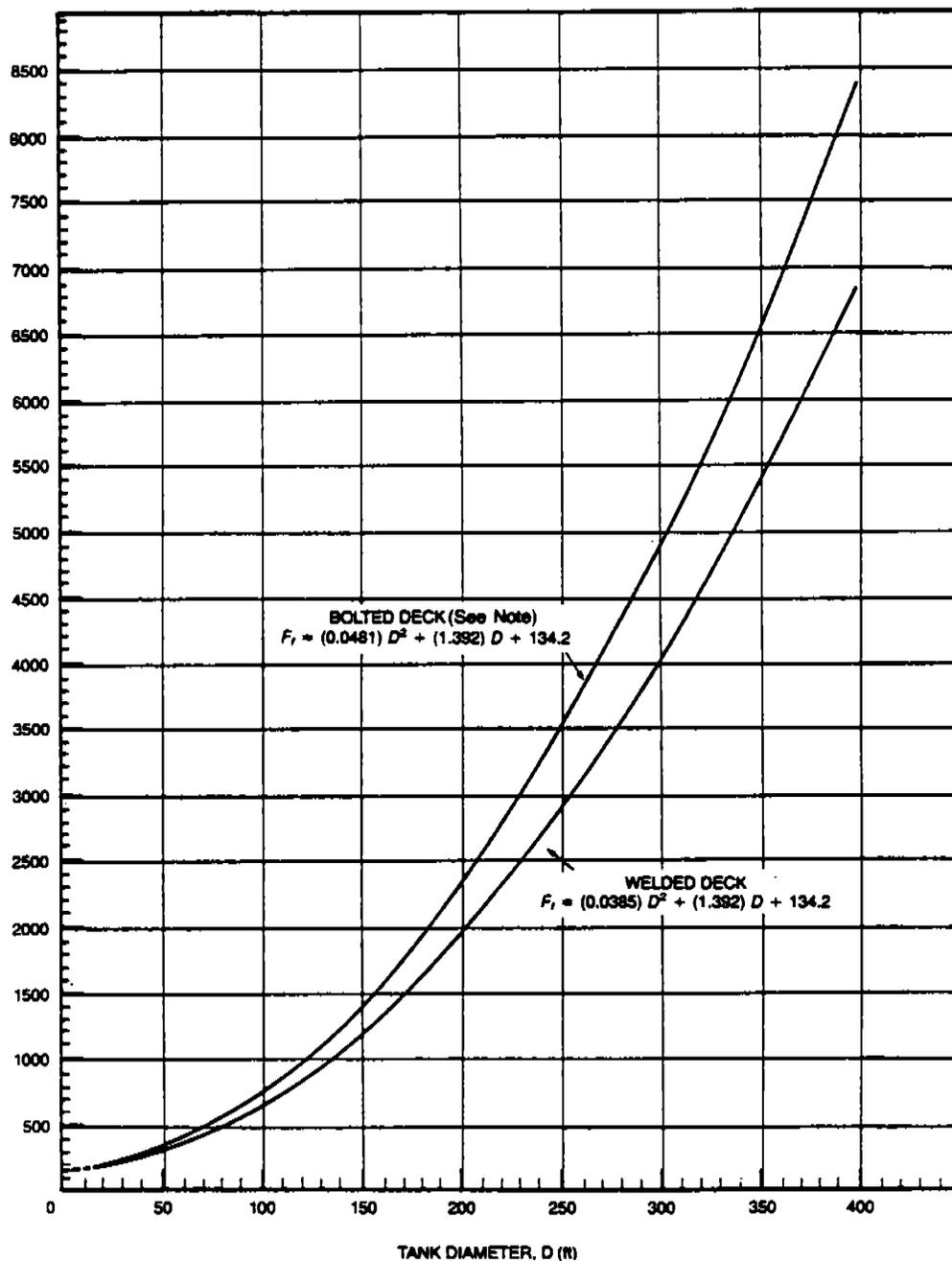
^aReference 1.

^bIf no specific information is available, this value can be assumed to represent the most common/typical deck fittings currently used.

^cD = tank diameter (ft).

^dNot used on welded contact internal floating decks.

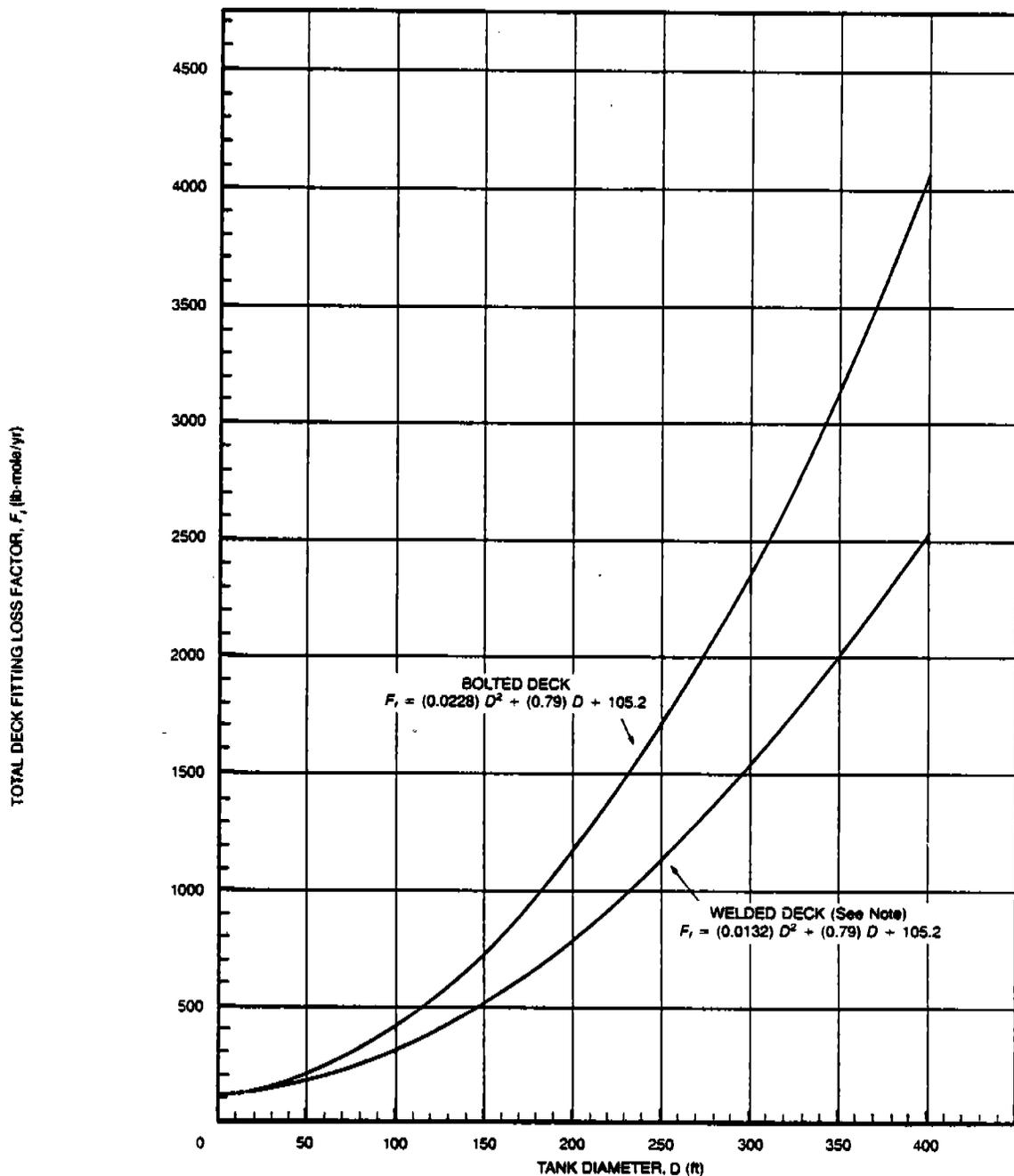
TOTAL DECK FITTING LOSS FACTOR, F_f (lb-mole/yr)



Basis: Fittings include: (1) access hatch, with ungasketed, unbolting cover; (2) built-up column wells, with ungasketed, sliding cover; (3) adjustable deck legs; (4) gauge floor well, with ungasketed, unbolting cover; (5) ladder well, with ungasketed sliding cover; (6) sample well, with slit fabric seal (10 percent open area); (7) 1-inch diameter stub drains (only on bolted deck); and (8) vacuum breaker, with gasketed weighted mechanical actuation. This basis was derived from a survey of users and manufacturers. Other fittings may be typically used within particular companies or organizations to reflect standards and/or specifications of that group. This figure should not supersede information based on actual tank data.

Note: If no specific information is available, assume bolted decks are the most common/typical type currently in use in tanks with column-supported fixed roofs.

Figure 4.3-10. Approximated total deck fitting loss factors (F_f) for typical fittings in tanks with column supported fixed roofs and either a bolted deck or a welded deck.⁶ This figure is to be used only when tank specific data on the number and kind of deck fittings are unavailable.



BASIS: Fittings include: (1) access hatch, with ungasketed, unbolted cover; (2) adjustable deck legs; (3) gauge float well, with ungasketed, unbolted cover; (4) sample well, with slit fabric seal (10 percent open area); (5) 1-inch diameter stub drains (only on bolted deck); and (6) vacuum breaker, with gasketed weighted mechanical actuation. This basis was derived from a survey of users and manufacturers. Other fittings may be typically used within particular companies or organizations to reflect standards and/or specifications of that group. This figure should not supersede information based on actual tank data.

NOTES: If no specific information is available, assume welded decks are the most common/typical type currently in use in tanks with self-supporting fixed roofs.

Figure 4.3-11. Approximated total deck fitting loss factors (F_f) for typical deck fittings in tanks with self-supporting fixed roofs and either a bolted deck or a welded deck.⁶ This figure is to be used only when tank specific data on the number and kind of deck fittings are unavailable.

where:

L_{seam} = total length of deck seams (ft)

A_{deck} = area of deck (ft²) = $\pi D^2/4$

D, P*, M_V, K_C = as defined for Equation 4

If the total length of the deck seam is not known, Table 4.3-8 can be used to determine S_D. Where tank specific data concerning width of deck sheets or size of deck panels are unavailable, a default value for S_D can be assigned. A value of 0.20 (ft/ft²) can be assumed to represent the most common bolted decks currently in use.

TABLE 4.3-8. DECK SEAM LENGTH FACTORS (S_D) FOR TYPICAL DECK CONSTRUCTIONS FOR INTERNAL FLOATING ROOF TANKS^a

Deck construction	Typical deck seam length factor, S _D (ft/ft ²)
Continuous sheet construction ^b	
5 ft wide	0.20 ^c
6 ft wide	0.17
7 ft wide	0.14
Panel construction ^d	
5 x 7.5 ft rectangular	0.33
5 x 12 ft rectangular	0.28

^aReference 6. Deck seam loss applies to bolted decks only.

^b $S_D = \frac{1}{W}$, where W = sheet width (ft)

^cIf no specific information is available, these factors can be assumed to represent the most common bolted decks currently in use.

^d $S_D = \frac{(L+W)}{LW}$, where W = panel width (ft) and L = panel length (ft)

Pressure Tanks - Losses occur during withdrawal and filling operations in low pressure (2.5 to 15 psig) tanks when atmospheric venting occurs. High pressure tanks are considered closed systems, with virtually no emissions. Vapor recovery systems are often found on low pressure tanks. Fugitive losses are also associated with pressure tanks and their equipment, but

with proper system maintenance, these losses are considered insignificant. No appropriate correlations are available to estimate vapor losses from pressure tanks.

Variable Vapor Space Tanks - Variable vapor space filling losses result when vapor is displaced by liquid during filling operations. Since the variable vapor space tank has an expandable vapor storage capacity, this loss is not as large as the filling loss associated with fixed roof tanks. Loss of vapor occurs only when the tank's vapor storage capacity is exceeded.

Variable vapor space system filling losses can be estimated from:³⁻⁷

$$L_V = (2.40 \times 10^{-2}) \frac{M_V P}{V_1} ((V_1) - (0.25 V_2 N_2)) \quad (8)$$

where:

L_V = variable vapor space filling loss (lb/10³ gal throughput)

M_V = molecular weight of vapor in storage tank (lb/lb-mole), see Note 1 to Equation 1

P = true vapor pressure at bulk liquid conditions (psia), see Note 2 to Equation 1

V_1 = volume of liquid pumped into system, throughput (bbl)

V_2 = volume expansion capacity of system (bbl), see Note 1

N_2 = number of transfers into system (dimensionless), see Note 2

Notes: (1) V_2 is the volume expansion capacity of the variable vapor space achieved by roof lifting or diaphragm flexing.

(2) N_2 is the number of transfers into the system during the time period that corresponds to a throughput of V_1 .

The accuracy of Equation 8 is not documented. Special tank operating conditions may result in actual losses significantly different from the estimates provided by Equation 8. It should also be noted that, although not developed for use with heavier petroleum liquids such as kerosenes and fuel oils, the equation is recommended for use with heavier petroleum liquids in the absence of better data.

4.3.3 Sample Calculations

Three sample calculations to estimate emission losses are provided, fixed roof tank, external floating roof tank, and internal floating roof

tank. Note that the same tank size, tank painting, stored product, and ambient conditions are employed in each sample calculation. Only the type of roof varies.

Problem I - Estimate the total loss from a fixed roof tank for 3 months based on data observed during the months of March, April and May and given the following information:

Tank description: Fixed roof tank; 100 ft diameter; 40 ft height; tank shell and roof painted specular aluminum color.

Stored product: Motor gasoline (petroleum liquid); Reid vapor pressure (RVP), 10 psia; 6.1 lb/gal liquid density; no vapor or liquid composition given; 375,000 bbl throughput for the 3 months.

Ambient conditions: 60°F average ambient temperature for the 3 months; 10 mi/hr average wind speed at the tank site for the 3 months; assume 14.7 psia atmospheric pressure; average maximum daily temperature, 68°F; average minimum daily temperature, 47°F.

Calculation: Total loss = breathing loss + working loss.

(a) Breathing Loss - Calculate using Equation 1.

$$L_B = 2.26 \times 10^{-2} M_V \left(\frac{P}{P_A - P} \right)^{0.68} D^{1.73} H^{0.51} \Delta T^{0.50} F_P C K_C \quad (1)$$

where:

L_B = breathing loss (lb/yr)

M_V = 66 lb/lb-mole (from Table 4.3-2 and RVP 10 gasoline)

T_A = 60°F (given)

T_S = 62.5°F (from Table 4.3-3, for an aluminum color tank in good condition and $T_A = 60^\circ\text{F}$)

RVP = 10 psia (given)

P_A = 14.7 psia (assumed)

P = 5.4 psia (from Figure 4.3-6, for 10 psia Reid vapor pressure gasoline and $T_S = 62.5^\circ\text{F}$)

D = 100 ft (given)

H = 20 ft (assumed $H = \frac{1}{2}$ tank height)

$\Delta T = 21^\circ\text{F}$ (average daily maximum, 68°F , minus average daily minimum, 47°F)

$F_p = 1.20$ (from Table 4.3-1 and given specular aluminum tank color)

$C = 1.0$ (tank diameter is larger than 30 ft)

$K_C = 1.0$ (value appropriate for all organic liquids except crude oil)

L_B (lb/yr) =

$$(2.26 \times 10^{-2})(66) \left(\frac{5.4}{14.7-5.4} \right)^{0.68} (100)^{1.73} (20)^{0.51} (21)^{0.50} (1.20)(1.0)(1.0) = 75,323 \text{ lb/yr}$$

For the 3 months, $L_B = \frac{75,323}{4} = 18,831 \text{ lb}$

(b) Working Loss - Calculate using Equation 2.

$$L_W = 2.40 \times 10^{-5} M_V P V N K_C \quad (2)$$

where:

L_W = working loss (lb/yr)

$M_V = 66 \text{ lb/lb-mole}$ (from Table 4.3-1 and RVP 10 gasoline)

$P = 5.4 \text{ psia}$ (calculated for breathing loss above)

$V = 2,350,000 \text{ gal}$

$$\text{where: } V \text{ (cubic feet)} = \frac{\pi D^2 h}{4}$$

$$\pi = 3.141$$

$$D = 100 \text{ ft}$$

$$h = 40 \text{ ft}$$

$$V = \frac{3.141(100)^2(40)}{4}$$

$$= 314,100 \text{ cubic ft}$$

$$V \text{ (gal)} = (7.48 \text{ gal/ft}^3) V \text{ (ft}^3)$$

$$V \text{ (gal)} = 7.48 (314,100) = 2,349,468 \text{ gal, round to } 2,350,000 \text{ gal}$$

$$N = \frac{\text{throughput/year}}{\text{tank volume}}$$

$$= \frac{(375,000 \text{ bbl})(4)(42 \text{ gal/bbl})}{2,350,000 \text{ gal}} = 26.8$$

$K_N = 1.0$ (from Figure 4.3-7 and $N = 26.8$)

$K_C = 1.0$ (value appropriate for all organic liquids except crude oil)

L_W (lb/yr) =

$$2.40 \times 10^{-5} (66)(5.4)(2.35 \times 10^6)(26.8)(1.0)(1.0) = 538,705 \text{ lb/yr}$$

For the 3 months, $L_W = \frac{538,705}{4} = 134,676 \text{ lb}$

(c) Total Loss for the 3 months -

$$L_T = L_B + L_W$$

$$= 18,831 + 134,676$$

$$= 153,507 \text{ lb}$$

Problem II - Estimate the total loss from an external floating roof tank for 3 months, based on data observed during the months of March, April and May and given the following information:

Tank description: External floating roof tank with a mechanical (metallic) shoe primary seal in good condition; 100 ft diameter; welded tank; shell and roof painted aluminum color.

Stored product: Motor gasoline (petroleum liquid); Reid vapor pressure, 10 psia; 6.1 lb/gal liquid density; no vapor or liquid composition given; 375,000 bbl throughput for the 3 months.

Ambient conditions: 60°F average ambient temperature for the 3 months; 10 mi/hr average wind speed at tank site for the 3 months; assume 14.7 psia atmospheric pressure.

Calculation: Total loss = rim seal loss + withdrawal loss + deck fitting loss + deck seam loss.

(a) Rim Seal Loss - Calculate the yearly rim seal loss from Equation 4.

$$L_R = K_S V^n P^* D M_V K_C \quad (4)$$

where:

L_R = rim seal loss (lb/yr)

$K_S = 1.2$ (from Table 4.3-4, for a welded tank with a mechanical shoe primary seal; note that external floating roofs have welded decks only)

$n = 1.5$ (from Table 4.3-4, for a welded tank with a mechanical shoe primary seal)

$V = 10$ mi/hr (given)

$T_A = 60^\circ\text{F}$ (given)

$T_S = 62.5^\circ\text{F}$ (from Table 4.3-3, for an aluminum color tank in good condition and $T_A = 60^\circ\text{F}$)

RVP = 10 psia (given)

$P = 5.4$ psia (from Figure 4.3-6, for 10 psia Reid vapor pressure gasoline and $T_S = 62.5^\circ\text{F}$)

$P_A = 14.7$ psia (assumed)

$$P^* = \frac{\left(\frac{5.4}{14.7}\right)}{\left(1 + \left(1 - \frac{5.4}{14.7}\right)^{0.5}\right)^2} = 0.114$$

(can also be determined from Figure 4.3-9 for $P = 5.4$ psia)

$D = 100$ ft (given)

$M_V = 66$ lb/lb-mole (from Table 4.3-2 and RVP 10 gasoline)

$K_C = 1.0$ (value appropriate for all organic liquids except crude oil)

To calculate yearly rim seal loss based on the 3 month data, multiply the K_S , K_C , P^* , D , M_V , and V^n values, as in Equation 4.

$$\begin{aligned} L_R &= (1.2)(10)^{1.5}(0.114)(100)(66)(1.0) \\ &= 28,551 \text{ lb/yr} \end{aligned}$$

For the 3 months, $L_R = \frac{(28,551)}{4} = 7,138$ lb

(b) Withdrawal Loss - Calculate the withdrawal loss from Equation 5.

$$L_W = (0.943) \frac{QCW_L}{D} \left[1 + \left(\frac{N_{CF}}{D} \right) \right] \quad (5)$$

where:

L_W = withdrawal loss (lb/yr)

$Q = 3.75 \times 10^5$ bbl for 3 months = 1.5×10^6 bbl/yr (given)

$C = 0.0015$ bbl/1,000 ft² (from Table 4.3-5, for gasoline in a steel tank with light rust assumed for tank in good condition as given)

$W_L = 6.1$ lb/gal (given)

$D = 100$ ft (given)

$N_C = 0$ (value for external floating roof tanks)

$F_C = 1.0$ (default value when column diameter is unknown; however, there are no columns in this tank, and an F_C value is used only for calculation purposes)

To calculate yearly withdrawal loss, use Equation 5.

$$L_W \text{ (lb/yr)} = \frac{(0.943)(1.5 \times 10^6)(0.0015)(6.1)}{100} \left(1 + \frac{(0.0)(1.0)}{100} \right)$$
$$= 129 \text{ lb/yr}$$

To calculate withdrawal loss for 3 months, divide by 4.

For the 3 months, $L_W = 129/4 = 32$ lb

- (c) Deck Fitting Loss - As stated, deck fitting loss estimation procedures for external floating roof tanks are not available. The deck fitting loss for the 3-month period is unknown and will be assumed to 0.
- (d) Deck Seam Loss - External floating roof tanks have welded decks; therefore, there are no deck seam losses.
- (e) Total Loss for the 3 months - Calculate the total loss using Equation 3.

$$L_T = L_R + L_W + L_F + L_D \quad (3)$$

where:

$L_T =$ total loss (lb/3 mo)

$L_R = 7,138$ lb/3 mo

$L_W = 32$ lb/3 mo

$L_F = 0$ (assumed)

$L_D = 0$

$$L_T = 7,138 + 32 + 0 + 0$$
$$= 7,170 \text{ lb/3 mo}$$

Problem III - Estimate the total loss for 3 months from an internal floating roof tank based on data observed during the months of March, April and May and given the following information:

- Tank description: Freely vented internal floating roof tank; contact deck made of welded 5 ft wide continuous sheets, with vapor mounted resilient seal; the fixed roof is supported by 6 pipe columns; tank shell and roof painted aluminum; 100 ft diameter.
- Stored product: Motor gasoline (petroleum liquid); Reid vapor pressure of 10 psia; 6.1 lb/gal liquid density; no vapor or liquid composition given; 375,000 bbl throughput for the 3 months.
- Ambient conditions: 60°F average ambient temperature for the 3 months; 10 mi/hr average wind speed at the tank site for the 3 months; assume 14.7 psia atmospheric pressure.
- Calculation: Total loss = rim seal loss + withdrawal loss + deck fitting loss + deck seam loss.

(a) Rim Seal Loss - Calculate yearly rim seal loss using Equation 4.

$$L_R = K_S V^n P^* D M_V K_C \quad (4)$$

where:

L_R = rim seal loss (lb/yr)

K_S = 6.7 (from Table 4.3-4; for a welded tank with a vapor mounted resilient seal and no secondary seal)

V = 10 mi/hr (given)

n = 0 (from Table 4.3-4 for a welded tank with a vapor mounted resilient seal and no secondary seal)

P^* = 0.114 (calculated in Problem II)

D = 100 ft (given)

M_V = 66 lb/lb-mole (from Table 4.3-2 and RVP 10 gasoline)

K_C = 1.0 (value appropriate for all organic liquids except crude oil)

$$\begin{aligned} L_R &= 6.7(10)^0(0.114)(100)(66)(1.0) \\ &= 5,041 \text{ lb/yr} \end{aligned}$$

For the 3 months, $L_R = \frac{5,041}{4} = 1,260 \text{ lb}$

(b) Withdrawal Loss - Calculate using Equation 5.

$$L_W = (0.943) \frac{QCW_L}{D} \left[1 + \left(\frac{N_C F_C}{D} \right) \right] \quad (5)$$

where:

L_W = withdrawal loss (lb/yr)

Q = 1.5×10^6 bbl/yr (calculated in Problem II)

C = 0.0015 bbl/1,000 ft² (from Table 4.3-5, light rust)

W_L = 6.1 lb/gal (given)

D = 100 ft (given)

N_C = 6 (given)

F_C = 1.0 (default value since column construction details are unknown)

$$L_W = \frac{(0.943)(1.5 \times 10^6)(0.0015)(6.1)}{100} \left[1 + \left(\frac{(6)(1.0)}{100} \right) \right]$$

$$= 137 \text{ lb/yr}$$

For the 3 months, $L_W = \frac{137}{4} = 34 \text{ lb}$

(c) Deck Fitting Loss - Calculate using Equation 6.

$$L_F = F_F P^* M_V K_C \quad (6)$$

where:

L_F = deck fitting loss (lb/yr)

F_F = 700 lb-mole/yr (interpreted from Figure 4.3-10, given tank diameter of 100 ft)

P^* = 0.114 (calculated in Problem II)

M_V = 66 lb/lb-mole (from Table 4.3-2 and RVP 10 gasoline)

K_C = 1.0 (value appropriate for all liquid organics except crude oil)

$$L_F = 700(0.114)(66)(1.0)$$

$$= 5,267 \text{ lb/yr}$$

For the 3 months, $L_F = \frac{5,267}{4} = 1,317 \text{ lb}$

(d) Deck Seam Loss - Calculate using Equation 7.

$$L_D = K_D S_D D^2 P^* M_V K_C \quad (7)$$

where:

L_D = deck seam loss (lb/yr)

K_D = 0 for welded seam deck, therefore

L_D = 0

(e) Total Loss for 3 months - Calculate from Equation 3.

$$L_T = L_R + L_W + L_F + L_D \quad (3)$$

where:

L_T = total loss (lb/yr)

L_R = 1,260 lb/3 mo

L_W = 34 lb/3 mo

L_F = 1,317 lb/3 mo

L_D = 0

$$L_T = 1,260 + 34 + 1,317 + 0$$

For the 3 months, L_T = 2,611 lb

References for Section 4.3 -

1. VOC Emissions From Volatile Organic Liquid Storage Tanks - Background Information for Proposed Standards, EPA-450/3-81-003a, U. S. Environmental Protection Agency, Research Triangle Park, NC, July 1984.
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3. Petrochemical Evaporation Loss From Storage Tanks, Bulletin No. 2523, American Petroleum Institute, New York, NY, 1969.
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5. Evaporation Loss From External Floating Roof Tanks, Second Edition, Bulletin No. 2517, American Petroleum Institute, Washington, D. C., 1980.

6. Evaporation Loss From Internal Floating Roof Tanks, Third Edition,
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1983.
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Bulletin No. 2520, American Petroleum Institute, New York, NY, 1964.



4.4 TRANSPORTATION AND MARKETING OF PETROLEUM LIQUIDS¹⁻³

4.4.1 General

The transportation and marketing of petroleum liquids involve many distinct operations, each of which represents a potential source of evaporation loss. Crude oil is transported from production operations to a refinery by tankers, barges, rail tank cars, tank trucks and pipelines. Refined petroleum products are conveyed to fuel marketing terminals and petrochemical industries by these same modes. From the fuel marketing terminals, the fuels are delivered by tank trucks to service stations, commercial accounts and local bulk storage plants. The final destination for gasoline is usually a motor vehicle gasoline tank. Similar distribution paths exist for fuel oils and other petroleum products. A general depiction of these activities is shown in Figure 4.4-1.

4.4.2 Emissions and Controls

Evaporative emissions from the transportation and marketing of petroleum liquids may be separated, by storage equipment and mode of transportation used, into four categories:

1. Rail tank cars, tank trucks and marine vessels: Loading, transit and ballasting losses.
2. Service stations: Bulk fuel drop losses and underground tank breathing losses.
3. Motor vehicle tanks: Refueling losses.
4. Large storage tanks: Breathing, working and standing storage losses. These are discussed in Section 4.3.

Evaporative and exhaust emissions are also associated with motor vehicle operation, and these topics are discussed in AP-42, Volume II: Mobile Sources.

Rail Tank Cars, Tank Trucks and Marine Vessels - Emissions from these sources are due to loading losses, ballasting losses and transit losses.

Loading Losses - Loading losses are the primary source of evaporative emissions from rail tank car, tank truck and marine vessel operations. Loading losses occur as organic vapors in "empty" cargo tanks are displaced to the atmosphere by the liquid being loaded into the tanks. These vapors are a composite of (1) vapors formed in the empty tank by evaporation of residual product from previous loads, (2) vapors transferred to the tank in vapor balance systems as product is being unloaded, and (3) vapors generated in the tank as the new product is being loaded. The quantity of evaporative losses from loading operations is, therefore, a function of the following parameters.

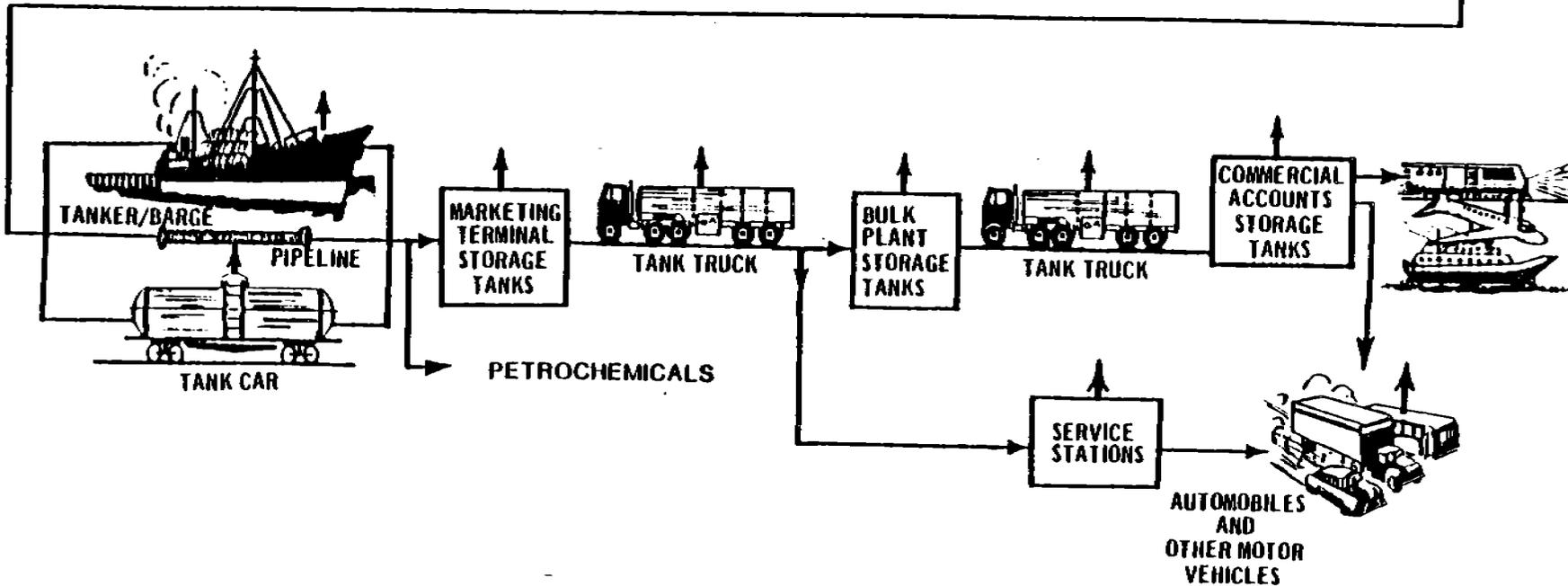
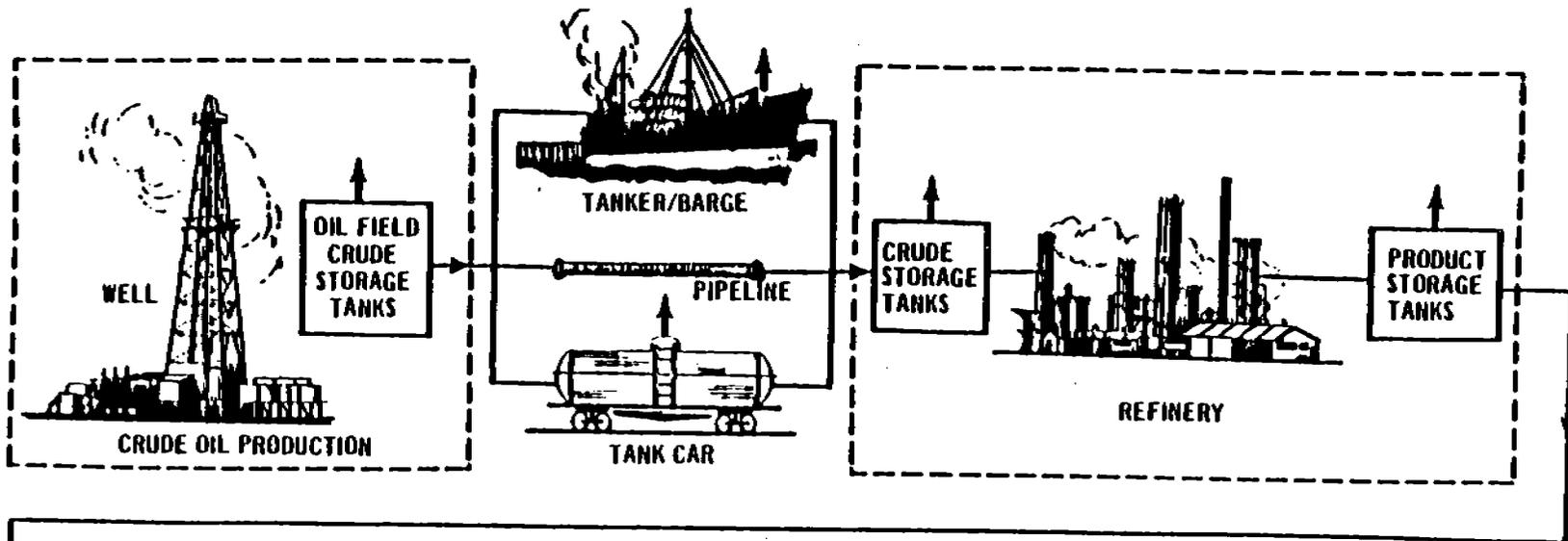


Figure 4.4-1. Flowsheet of petroleum production, refining, and distribution systems. (Sources of organic evaporative emissions are indicated by vertical arrows.)

- Physical and chemical characteristics of the previous cargo.
- Method of unloading the previous cargo.
- Operations to transport the empty carrier to a loading terminal.
- Method of loading the new cargo.
- Physical and chemical characteristics of the new cargo.

The principal methods of cargo carrier loading are illustrated in Figures 4.4-2 through 4.4-4. In the splash loading method, the fill pipe dispensing the cargo is lowered only partway into the cargo tank. Significant turbulence and vapor/liquid contact occur during the splash loading operation, resulting in high levels of vapor generation and loss. If the turbulence is great enough, liquid droplets will be entrained in the vented vapors.

A second method of loading is submerged loading. Two types are the submerged fill pipe method and the bottom loading method. In the submerged fill pipe method, the fill pipe extends almost to the bottom of the cargo tank. In the bottom loading method, a permanent fill pipe is attached to the cargo tank bottom. During most of both methods of submerged loading, the fill pipe opening is below the liquid surface level. Liquid turbulence is controlled significantly during submerged loading, resulting in much lower vapor generation than encountered during splash loading.

The recent loading history of a cargo carrier is just as important a factor in loading losses as the method of loading. If the carrier has carried a nonvolatile liquid such as fuel oil, or has just been cleaned, it will contain vapor free air. If it has just carried gasoline and has not been vented, the air in the carrier tank will contain volatile organic vapors, which are expelled during the loading operation along with newly generated vapors.

Cargo carriers are sometimes designated to transport only one product, and in such cases are practicing "dedicated service". Dedicated gasoline cargo tanks return to a loading terminal containing air fully or partially saturated with vapor from the previous load. Cargo tanks may also be "switch loaded" with various products, so that a nonvolatile product being loaded may expel the vapors remaining from a previous load of a volatile product such as gasoline. These circumstances vary with the type of cargo tank and with the ownership of the carrier, the petroleum liquids being transported, geographic location, and season of the year.

One control measure for gasoline tank trucks is called "vapor balance service", in which the cargo tank retrieves the vapors displaced during product unloading at bulk plants or service stations and transports the vapors back to the loading terminal. Figure 4.4-5 shows a tank truck in vapor balance service filling a service station underground tank and taking on displaced gasoline vapors for return to the terminal. A cargo tank in vapor balance service normally is saturated with organic vapors, and the presence of these vapors at the start of submerged loading results in greater loading losses than encountered during nonvapor balance, or "normal", service. Vapor balance service is usually not practiced with

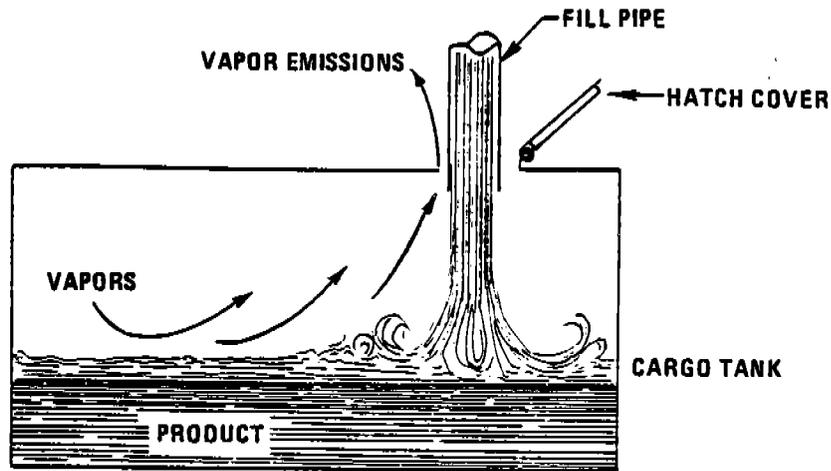


Figure 4.4-2. Splash loading method.

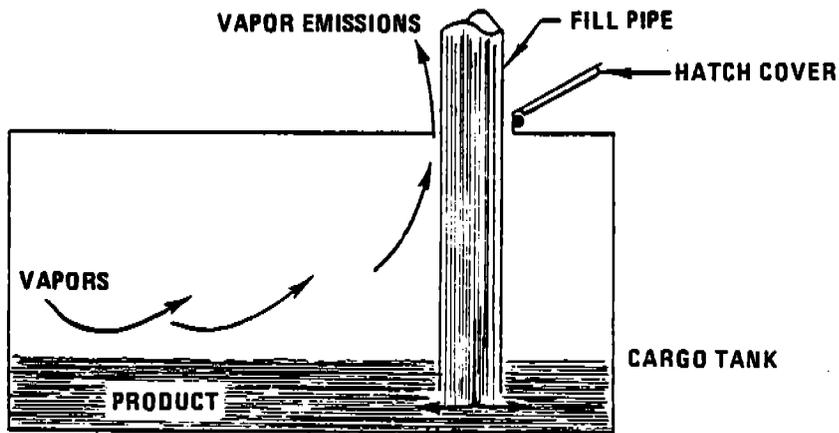


Figure 4.4-3. Submerged fill pipe.

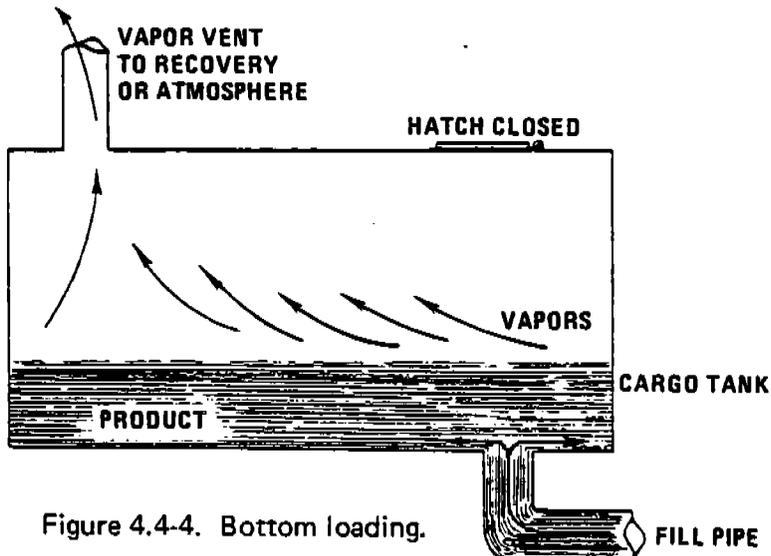


Figure 4.4-4. Bottom loading.

marine vessels, although some vessels practice emission control by means of vapor transfer within their own cargo tanks during ballasting operations (see page 4.4-10).

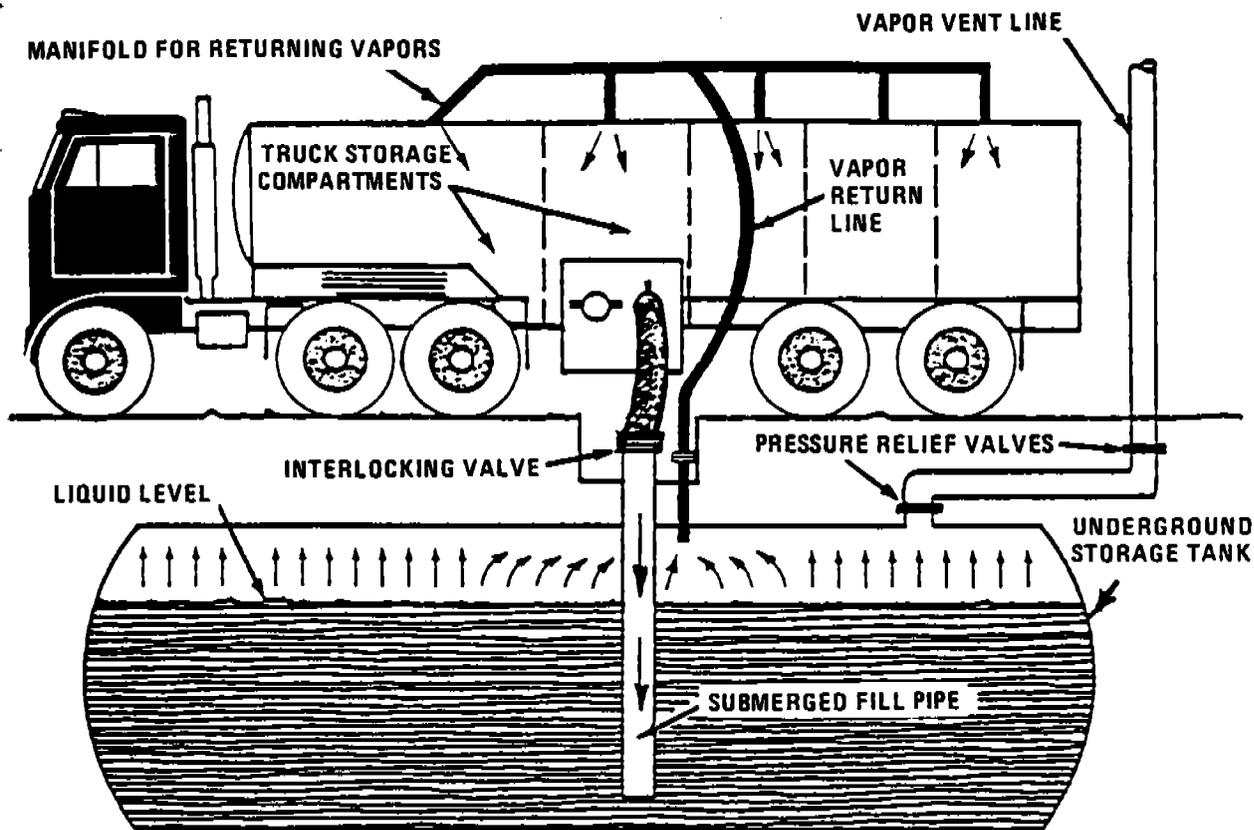


Figure 4.4-5. Tank truck unloading into a service station underground storage tank and practicing "vapor balance" form of emission control.

Emissions from loading petroleum liquid can be estimated (with a probable error of ± 30 percent)⁴ using the following expression:

$$L_L = 12.46 \frac{SPM}{T} \quad (1)$$

where: L_L = Loading loss, lb/10³ gal of liquid loaded
 M = Molecular weight of vapors, lb/lb-mole (see Table 4.3-2)
 P = True vapor pressure of liquid loaded, psia (see Figures 4.3-5 and 4.3-6 and Table 4.3-2)
 T = Temperature of bulk liquid loaded, °R (°F + 460)
 S = A saturation factor (see Table 4.4-1)

The saturation factor, S, represents the expelled vapor's fractional approach to saturation, and it accounts for the variations observed in emission rates from the different unloading and loading methods. Table 4.4-1 lists suggested saturation factors.

TABLE 4.4-1. SATURATION (S) FACTORS FOR CALCULATING PETROLEUM LIQUID LOADING LOSSES

Cargo carrier	Mode of operation	S factor
Tank trucks and rail tank cars	Submerged loading of a clean cargo tank	0.50
	Submerged loading: dedicated normal service	0.60
	Submerged loading: dedicated vapor balance service	1.00
	Splash loading of a clean cargo tank	1.45
	Splash loading: dedicated normal service	1.45
	Splash loading: dedicated vapor balance service	1.00
Marine vessels ^a	Submerged loading: ships	0.2
	Submerged loading: barges	0.5

^aFor products other than gasoline and crude oil. Use factors from Table 4.4-2 for marine loading of gasoline. Use Equations 2 and 3 and Table 4.4-3 for marine loading of crude oil.

Emissions from controlled loading operations can be calculated by multiplying the uncontrolled emission rate calculated in Equation 1 by the control efficiency term:

$$\left(1 - \frac{\text{eff}}{100}\right).$$

Measures to reduce loading emissions include selection of alternate loading methods and application of vapor recovery equipment. The latter captures organic vapors displaced during loading operations and recovers

the vapors by the use of refrigeration, absorption, adsorption and/or compression. The recovered product is piped back to storage. Vapors can also be controlled through combustion in a thermal oxidation unit, with no product recovery. Figure 4.4-6 demonstrates the recovery of gasoline vapors from tank trucks during loading operations at bulk terminals. Control efficiencies of modern units range from 90 to over 99 percent, depending on the nature of the vapors and the type of control equipment used.⁵⁻⁶

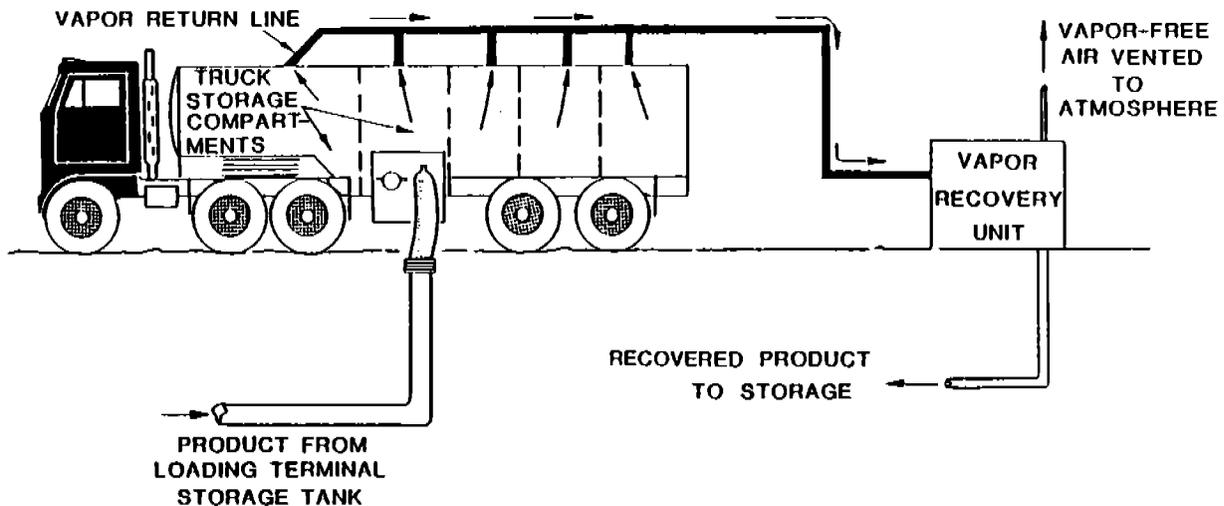


Figure 4.4-6. Tank truck loading with vapor recovery.

Sample Calculation - Loading losses (L_L) from a gasoline tank truck in dedicated vapor balance service and practicing vapor recovery would be calculated as follows, using Equation 1:

Design basis -

Cargo tank volume is 8,000 gallons
 Gasoline RVP is 9 psia
 Product temperature is 80°F
 Vapor recovery efficiency is 95%

Loading loss equation -

$$L_L = 12.46 \frac{SPM}{T} \left(1 - \frac{eff}{100} \right)$$

where: S = Saturation factor (see Table 4.4-1) = 1.00
 P = True vapor pressure of gasoline (see Figure 4.3-6) = 6.6 psia
 M = Molecular weight of gasoline vapors (see Table 4.3-2) = 66
 T = Temperature of gasoline = 540°R
 eff = Control efficiency = 95%

$$L_L = 12.46 \frac{(1.00)(6.6)(66)}{540} \left(1 - \frac{95}{100}\right)$$

$$= 0.50 \text{ lb}/10^3 \text{ gal}$$

Total loading losses are:

$$(0.50 \text{ lb}/10^3 \text{ gal})(8.0 \times 10^3 \text{ gal}) = 4.0 \text{ lb}$$

Measurements of gasoline loading losses from ships and barges have led to the development of emission factors for these specific loading operations.⁷ These factors are presented in Table 4.4-2 and, for gasoline loading operations at marine terminals, should be used instead of Equation 1.

In addition to Equation 1, which estimates emissions from the loading of petroleum liquids, Equation 2 has been developed specifically for estimating the emissions from the loading of crude oil into ships and ocean barges:

$$C_L = C_A + C_G \quad (2)$$

where: C_L = Total loading loss, $\text{lb}/10^3$ gal of crude oil loaded
 C_A = Arrival emission factor, contributed by vapors in the empty tank compartment prior to loading, $\text{lb}/10^3$ gal loaded (see Note)
 C_G = Generated emission factor, contributed by evaporation during loading, $\text{lb}/10^3$ gal loaded

This equation was developed empirically based on test measurements of several vessel compartments.⁷ The quantity C_G can be calculated using Equation 3:

$$C_G = 1.84 (0.44 P - 0.42) \frac{M G}{T} \quad (3)$$

where: P = True vapor pressure of loaded crude oil, psia (see Figure 4.3-5 and Table 4.3-2)
 M = Molecular weight of vapors, $\text{lb}/\text{lb-mole}$ (see Table 4.3-2)
 G = Vapor growth factor = 1.02 (dimensionless)
 T = Temperature of vapors, $^{\circ}\text{R}$ ($^{\circ}\text{F} + 460$)

Note - Values of C_A for various cargo tank conditions are listed in Table 4.4-3.

Emission factors derived from Equation 3 and Table 4.4-3 represent total organic compounds. Nonmethane-nonethane volatile organic compound (VOC) emission factors for crude oil vapors have been found to range from approximately 55 to 100 weight percent of these total organic factors. When specific vapor composition information is not available, the VOC emission factor can be estimated by taking 85 percent of the total organic factor.³

TABLE 4.4-2. VOLATILE ORGANIC COMPOUND EMISSION FACTORS FOR GASOLINE LOADING OPERATIONS AT MARINE TERMINALS^a

Vessel tank condition	Previous cargo	Total organic emission factors			
		Ships/ocean barges ^b		Barges ^b	
		mg/liter transferred	lb/10 ³ gal transferred	mg/liter transferred	lb/10 ³ gal transferred
Uncleaned	Volatile ^c	315	2.6	465	3.9
Ballasted	Volatile	205	1.7	d	d
Cleaned	Volatile	180	1.5	e	e
Gas-freed	Volatile	85	0.7	e	e
Any condition	Nonvolatile	85	0.7	e	e
Gas-freed	Any cargo	e	e	245	2.0
Typical overall situation ^f	Any cargo	215	1.8	410	3.4

^aReferences 2, 8. Factors represent nonmethane-nonethane VOC emissions because methane and ethane have been found to constitute a negligible weight fraction of the evaporative emissions from gasoline.

^bOcean barges (tank compartment depth about 40 feet) exhibit emission levels similar to tank ships. Shallow draft barges (compartment depth 10 to 12 feet) exhibit higher emission levels.

^cVolatile cargoes are those with a true vapor pressure greater than 1.5 psia.

^dBarges are not usually ballasted.

^eUnavailable.

^fBased on observation that 41% of tested ship compartments were uncleaned, 11% ballasted, 24% cleaned, and 24% gas-freed. For barges, 76% were uncleaned.

TABLE 4.4-3. AVERAGE ARRIVAL EMISSION FACTORS, C_A, FOR CRUDE OIL LOADING EMISSION EQUATION^a

Ship/ocean barge tank condition	Previous cargo	Arrival emission factor, lb/10 ³ gal
Uncleaned	Volatile ^b	0.86
Ballasted	Volatile	0.46
Cleaned or gas-freed	Volatile	0.33
Any condition	Nonvolatile	0.33

^aArrival emission factors (C_A) to be added to generated emission factors calculated in Equation 3 to produce total crude oil loading loss. These factors represent total organic compounds; nonmethane-nonethane VOC emission factors average about 15% lower.

^bVolatile cargoes are those with a true vapor pressure greater than 1.5 psia.

Ballasting Losses - Ballasting operations are a major source of evaporative emissions associated with the unloading of petroleum liquids at marine terminals. It is common practice to load several cargo tank compartments with sea water after the cargo has been unloaded. This water, termed "ballast", improves the stability of the empty tanker during the subsequent voyage. Although ballasting practices vary, individual cargo tanks are ballasted typically about 80 percent, and the total vessel is ballasted 15 to 40 percent, of capacity. Ballasting emissions occur as vapor laden air in the "empty" cargo tank is displaced to the atmosphere by ballast water being pumped into the tank. Upon arrival at a loading port, the ballast water is pumped from the cargo tanks before the new cargo is loaded. The ballasting of cargo tanks reduces the quantity of vapors returning in the empty tank, thereby reducing the quantity of vapors emitted during subsequent tanker loading. Regulations administered by the U. S. Coast Guard require that, at marine terminals located in ozone nonattainment areas, large tankers with crude oil washing systems contain organic vapors from ballasting.⁹ This is accomplished principally by displacing the vapors during ballasting into a cargo tank being simultaneously unloaded. Marine vessels in other areas emit organic vapors directly to the atmosphere.

Equation 4 has been developed from test data to calculate the ballasting emissions from crude oil ships and ocean barges⁷:

$$L_B = 0.31 + 0.20 P + 0.01 PU_A \quad (4)$$

where: L_B = Ballasting emission factor, lb/10³ gal of ballast water
 P = True vapor pressure of discharged crude oil, psia (see Figure 4.3-5 and Table 4.3-2)
 U_A = Arrival cargo true ullage, prior to dockside discharge, measured from the deck, feet. The term "ullage" refers to the distance between the cargo surface level and the deck level

Table 4.4-4 lists average total organic emission factors for ballasting into uncleaned crude oil cargo compartments. The first category applies to "full" compartments wherein the crude oil true ullage just prior to cargo discharge is less than 5 feet. The second category applies to lightered, or short-loaded, compartments (part of cargo previously discharged or original load a partial fill), with an arrival true ullage greater than 5 feet. It should be remembered that these tabulated emission factors are examples only, based on average conditions, to be used when crude oil vapor pressure is unknown. Equation 4 should be used when information about crude oil vapor pressure and cargo compartment condition is available. The sample calculation illustrates the use of Equation 4.

Sample Calculation - Ballasting emissions from a crude oil cargo ship would be calculated as follows, using Equation 4:

Design basis -

Vessel and cargo description:

80,000 dead-weight-ton tanker, crude oil capacity 500,000 barrels;
 20 percent of the cargo capacity is filled with ballast water after

TABLE 4.4-4. TOTAL ORGANIC EMISSION FACTORS FOR CRUDE OIL BALLASTING^a

Compartment condition before cargo discharge	Average emission factors			
	By category		Typical overall ^b	
	mg/liter ballast water	lb/10 ³ gal ballast water	mg/liter ballast water	lb/10 ³ gal ballast water
Fully loaded ^c	111	0.9	129	1.1
Lightered or previously short-loaded ^d	171	1.4		

^aAssumes crude oil temperature of 60°F and RVP of 5 psia. Nonmethane-nonethane VOC emission factors average about 85% of these total organic factors.

^bBased on observation that 70% of tested compartments had been fully loaded before ballasting. May not represent average vessel practices.

^cAssumed typical arrival ullage of 2 ft.

^dAssumed typical arrival ullage of 20 ft.

cargo discharge. The crude oil has an RVP of 6 psia and is discharged at 75°F.

Compartment conditions:

70 percent of the ballast water is loaded into compartments that had been fully loaded to 2 feet ullage, and 30 percent is loaded into compartments that had been lightered to 15 feet ullage before arrival at dockside.

Ballasting emission equation -

$$L_B = 0.31 + 0.20 P + 0.01 P U_A$$

where: P = True vapor pressure of crude oil (see Figure 4.3-5)
= 4.6 psia

U_A = True cargo ullage for the full compartments = 2 feet, and true cargo ullage for the lightered compartments = 15 feet

$$\begin{aligned} L_B &= 0.70 [0.31 + (0.20)(4.6) + (0.01)(4.6)(2)] \\ &\quad + 0.30 [0.31 + (0.20)(4.6) + (0.01)(4.6)(15)] \\ &= 1.5 \text{ lb}/10^3 \text{ gal} \end{aligned}$$

Total ballasting emissions are:

$$(1.5 \text{ lb}/10^3 \text{ gal})(0.20)(500,000 \text{ bbl})(42 \text{ gal}/\text{bbl}) = 6,300 \text{ lb}$$

Since VOC emissions average about 85% of these total organic emissions, emissions of VOC are about: (0.85)(6,300 lb) = 5,360 lb

Transit Losses - In addition to loading and ballasting losses, losses occur while the cargo is in transit. Transit losses are similar in many ways to breathing losses associated with petroleum storage (see Section 4.3). Experimental tests on ships and barges have indicated that transit losses can be calculated using Equation 5⁴:

$$L_T = 0.1 PW \quad (5)$$

where: L_T = Transit loss from ships and barges, lb/week-10³ gal transported
 P = True vapor pressure of the transported liquid, psia
(see Figures 4.3-5 and 4.3-6 and Table 4.3-2)
 W = Density of the condensed vapors, lb/gal (see Table 4.3-2)

Emissions from gasoline truck cargo tanks during transit have been studied by a combination of theoretical and experimental techniques, and typical emission values are presented in Table 4.4-5.¹⁰⁻¹¹ Emissions depend on the extent of venting from the cargo tank during transit, which in turn depends on the vapor tightness of the tank, the pressure relief valve settings, the pressure in the tank at the start of the trip, the vapor pressure of the fuel being transported, and the degree of fuel vapor saturation of the space in the tank. The emissions are not directly proportional to the time spent in transit. If the vapor leakage rate of the tank increases, emissions increase up to a point, and then the rate changes as other determining factors take over. Truck tanks in dedicated vapor balance service usually contain saturated vapors, and this leads to lower emissions during transit, because no additional fuel evaporates to raise the pressure in the tank to cause venting. Table 4.4-5 lists "typical" values for transit emissions and "extreme" values that could occur in the unlikely event that all determining factors combined to cause maximum emissions.

In the absence of specific inputs for Equations 1 through 5, the typical evaporative emission factors presented in Tables 4.4-5 and 4.4-6 should be used. It should be noted that, although the crude oil used to calculate the emission values presented in these tables has an RVP of 5, the RVP of crude oils can range from less than 1 up to 10. Similarly, the RVP of gasolines has a range of approximately 7 to 13. In areas where loading and transportation sources are major factors affecting air quality, it is advisable to obtain the necessary parameters and calculate emission estimates using Equations 1 through 5.

Service Stations - Another major source of evaporative emissions is the filling of underground gasoline storage tanks at service stations. Gasoline is usually delivered to service stations in large (8,000 gallon) tank trucks or smaller account trucks. Emissions are generated when gasoline vapors in the underground storage tank are displaced to the atmosphere by the gasoline being loaded into the tank. As with other loading losses, the quantity of the service station tank filling loss depends on several variables, including the method and rate of filling, the tank configuration, and the gasoline temperature, vapor pressure and composition. Using Equation (1), an average emission rate for submerged filling is 880 milligrams per liter of transferred gasoline, and the rate for splash filling is 1,380 milligrams per liter of transferred gasoline (see Table 4.4-7).⁵

TABLE 4.4-5 TOTAL ORGANIC EMISSION FACTORS FOR PETROLEUM
LIQUID RAIL TANK CARS AND TANK TRUCKS

Emission source	Gasoline ^a	Crude oil ^b	Jet naphtha (JP-4)	Jet kerosene	Distillate oil No. 2	Residual oil No. 6
Loading operations^c						
Submerged loading - dedicated normal service ^d						
mg/liter transferred	590	240	180	1.9	1.7	0.01
1b/10 ³ gal transferred	5	2	1.5	0.16	0.014	0.0001
Submerged loading - vapor balance service ^d						
mg/liter transferred	980	400	300	e	e	e
1b/10 ³ gal transferred	8	3	2.5	e	e	e
Splash loading - dedicated normal service						
mg/liter transferred	1,430	580	430	5	4	0.03
1b/10 ³ gal transferred	12	5	4	0.04	0.03	0.0003
Splash loading - vapor balance service						
mg/liter transferred	980	400	300	e	e	e
1b/10 ³ gal transferred	8	3	2.5	e	e	e
Transit losses						
Loaded with product						
mg/liter transported						
typical	0 - 1.0	f	f	f	f	f
extreme	0 - 9.0	f	f	f	f	f
1b/10 ³ gal transported						
typical	0 - 0.01	f	f	f	f	f
extreme	0 - 0.08	f	f	f	f	f
Return with vapor						
mg/liter transported						
typical	0 - 13.0	f	f	f	f	f
extreme	0 - 44.0	f	f	f	f	f
1b/10 ³ gal transported						
typical	0 - 0.11	f	f	f	f	f
extreme	0 - 0.37	f	f	f	f	f

^aReference 2. Gasoline factors represent emissions of nonmethane-nonethane VOC, since methane and ethane constitute a negligible weight fraction of the evaporative emissions from gasoline. The example gasoline has an RVP of 10 psia.

^bThe example crude oil has an RVP of 5 psia.

^cLoading emission factors are calculated using Equation 1 for a dispensed product temperature of 60°F.

^dReference 2.

^eNot normally used.

^fUnavailable.

TABLE 4.4-6. TOTAL ORGANIC EMISSION FACTORS FOR PETROLEUM MARINE VESSEL SOURCES^a

Emission source	Gasoline ^b	Crude oil ^c	Jet naphtha (JP-4)	Jet kerosene	Distillate oil No. 2	Residual oil No. 6
Loading operations						
Ships/ocean barges						
mg/liter transferred	d	73	60	0.63	0.55	0.004
lb/10 ³ gal transferred	d	0.61	0.50	0.005	0.005	0.00004
Barges						
mg/liter transferred	d	120	150	1.60	1.40	0.011
lb/10 ³ gal transferred	d	1.0	1.2	0.013	0.012	0.00009
Tanker ballasting						
mg/liter ballast water	100	e	f	f	f	f
lb/10 ³ gal ballast water	0.8	e	f	f	f	f
Transit						
mg/week-liter transported	320	150	84	0.60	0.54	0.003
lb/week-10 ³ gal transported	2.7	1.3	0.7	0.005	0.005	3 x 10 ⁻⁵

^aEmission factors are calculated for a dispensed product temperature of 60°F.

^bFactors shown for gasoline represent nonmethane-nonethane VOC emissions. The example gasoline has an RVP of 10 psia.

^cNonmethane-nonethane VOC emission factors for a typical crude oil are 15% lower than the total organic factors shown. The example crude oil has an RVP of 5 psia.

^dSee Table 4.4-2 for these emission factors.

^eSee Table 4.4-4 for these emission factors.

^fUnavailable.

Emissions from underground tank filling operations at service stations can be reduced by the use of a vapor balance system such as in Figure 4.4-5 (termed Stage I vapor control). The vapor balance system employs a hose that returns gasoline vapors displaced from the underground tank to the tank truck cargo compartments being emptied. The control efficiency of the balance system ranges from 93 to 100 percent. Organic emissions from underground tank filling operations at a service station employing a vapor balance system and submerged filling are not expected to exceed 40 milligrams per liter of transferred gasoline.

A second source of vapor emissions from service stations is underground tank breathing. Breathing losses occur daily and are attributable to gasoline evaporation and barometric pressure changes. The frequency with which gasoline is withdrawn from the tank, allowing fresh air to enter to enhance evaporation, also has a major effect on the quantity of these emissions. An average breathing emission rate is 120 milligrams per liter of throughput.

TABLE 4.4-7. EVAPORATIVE EMISSIONS FROM GASOLINE SERVICE STATION OPERATIONS

Emission source	Emission rate	
	mg/liter throughput	lb/10 ³ gal throughput
Filling underground tank		
Submerged filling ^a	880	7.3
Splash filling ^a	1,380	11.5
Balanced submerged filling	40	0.3
Underground tank breathing and emptying ^b	120	1.0
Vehicle refueling operations		
Displacement losses (uncontrolled)	1,320	11.0
Displacement losses (controlled)	132	1.1
Spillage	80	0.7

^aThese factors are calculated using Equation 1 for a gasoline temperature of 60°F and RVP of 10 psia.

^bIncludes any vapor loss between underground tank and gas pump.

Motor Vehicle Refueling - Service station vehicle refueling activity also produces evaporative emissions. Vehicle refueling emissions come from vapors displaced from the automobile tank by dispensed gasoline and from spillage. The quantity of displaced vapors depends on gasoline temperature, auto tank temperature, gasoline RVP and dispensing rate. It is estimated that the uncontrolled emissions from vapors displaced during vehicle refueling average 1,320 milligrams per liter of dispensed gasoline.^{5,12}

Spillage loss is made up of contributions from prefill and postfill nozzle drip and from spit-back and overflow from the vehicle's fuel tank filler pipe during filling. The amount of spillage loss can depend on several variables, including service station business characteristics, tank configuration, and operator techniques. An average spillage loss is 80 milligrams per liter of dispensed gasoline.^{5,12}

Control methods for vehicle refueling emissions are based on conveying the vapors displaced from the vehicle fuel tank to the underground storage tank vapor space through the use of a special hose and nozzle, as depicted in Figure 4.4-7 (termed Stage II vapor control). In "balance" vapor control systems, the vapors are conveyed by natural pressure differentials established during refueling. In "vacuum assist" systems, the conveyance of vapors from the auto fuel tank to the underground storage tank is assisted by a vacuum pump. Although vapor control systems for vehicle refueling activity are not currently in widespread operation at service stations, tests on a few systems have indicated overall system control efficiencies in the range of 88 to 92 percent.^{5,12}

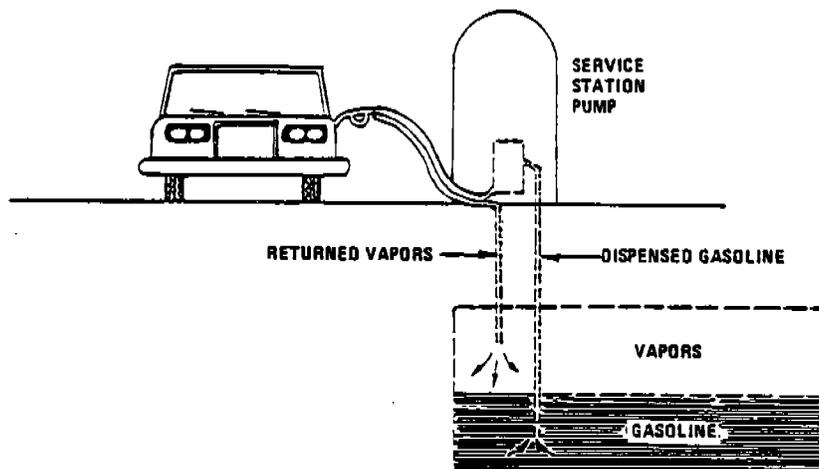


Figure 4.4-7. Automobile refueling vapor recovery system.

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8.11 GLASS FIBER MANUFACTURING

8.11.1 General

Glass fiber manufacturing is the high temperature conversion of various raw materials (predominantly borosilicates) into a homogeneous melt, followed by the fabrication of this melt into glass fibers. The two basic types of glass fiber products, textile and wool, are manufactured by similar processes. A typical diagram of these processes is shown in Figure 8.11-1. Glass fiber production can be segmented into three phases: raw materials handling, glass melting and refining, and fiber forming and finishing, this last phase being slightly different in textile and the wool glass fiber production.

Raw Materials Handling - The primary component of glass fiber is sand, but it also includes varying quantities of feldspar, sodium sulfate, anhydrous borax, boric acid, and many other materials. The bulk supplies are received by rail car and truck, and the lesser volume supplies are received in drums and packages. These raw materials are unloaded by a variety of methods, including drag shovels, vacuum systems and vibrator/gravity systems. Conveying to and from storage piles and silos is accomplished by belts, screws and bucket elevators. From storage, the materials are weighed according to the desired product recipe and then blended well before their introduction into the melting unit. The weighing, mixing and charging operations may be conducted in either batch or continuous mode.

Glass Melting And Refining - In the glass melting furnace, the raw materials are heated to temperatures ranging from 1500° to 1700°C (2700° to 3100°F) and are transformed through a sequence of chemical reactions to molten glass. Although there are many furnace designs, furnaces are generally large, shallow and well insulated vessels which are heated from above. In operation, raw materials are introduced continuously on top of a bed of molten glass, where they slowly mix and dissolve. Mixing is effected by natural convection, gases rising from chemical reactions, and in some operations, by air injection into the bottom of the bed.

Glass melting furnaces can be categorized, by their fuel source and method of heat application, into four types: recuperative, regenerative, unit, and electric melter. The recuperative, regenerative, and unit melter furnaces can be fueled by either gas or oil. The current trend is from gas fired to oil fired. Recuperative furnaces use a steel heat exchanger, recovering heat from the exhaust gases by exchange with the combustion air. Regenerative furnaces use a lattice of brickwork to recover waste heat from exhaust gases. In the initial mode of operation, hot exhaust gases are routed through a chamber containing a brickwork lattice, while combustion air is heated by passage through another corresponding brickwork lattice. About every twenty minutes, the air flow is reversed, so that the combustion air is always being passed through hot brickwork previously heated by exhaust gases. Electric furnaces melt glass by passing an electric current through the melt. Electric furnaces are either hot top or cold top. The former use gas for auxiliary heating, and the latter use only the electric current.

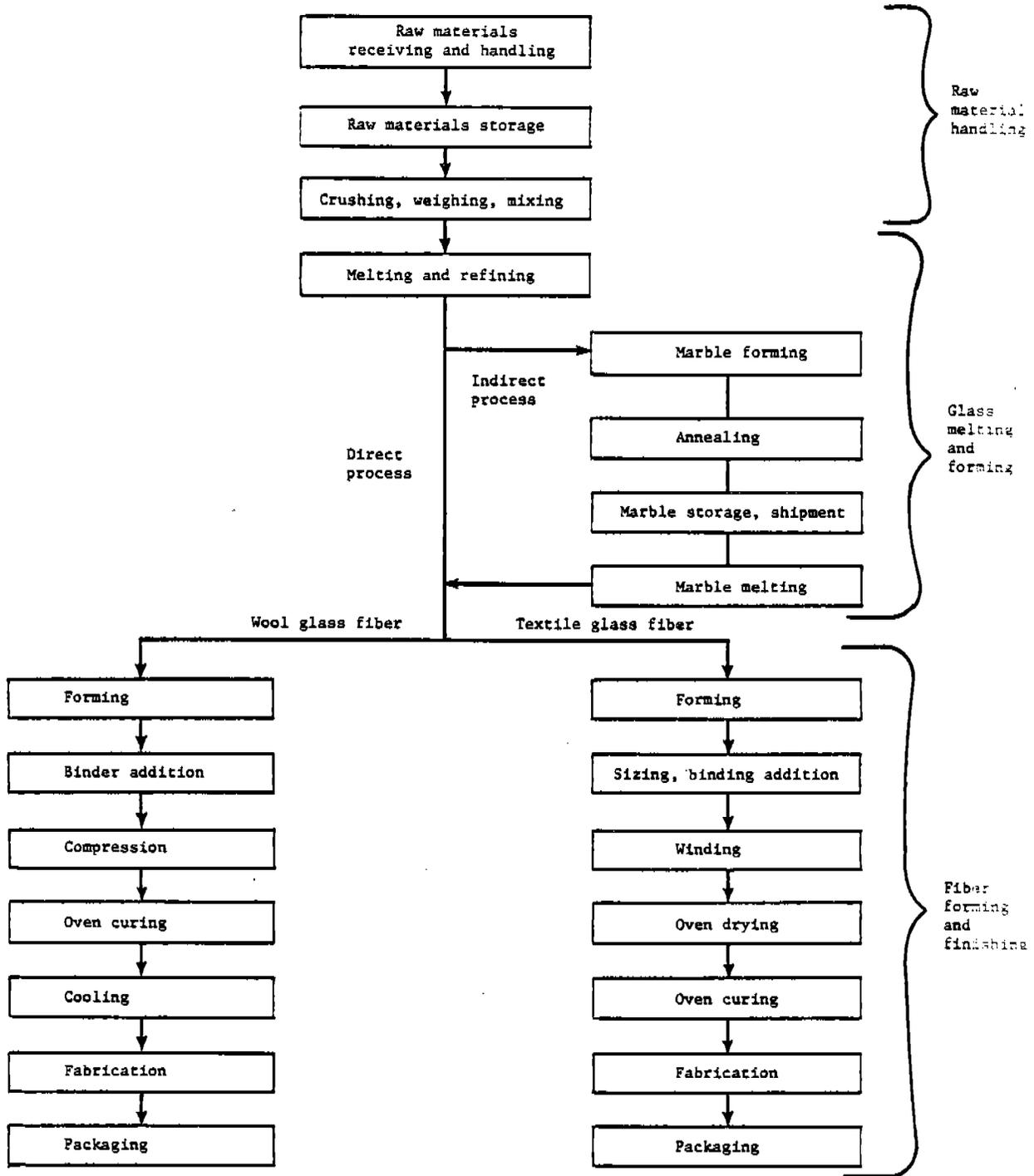


Figure 8.11-1. Typical flow diagram of the glass fiber production process.

Electric furnaces are currently used only for wool glass fiber production, because of the electrical properties of the glass formulation. Unit melters are used only for the "indirect" marble melting process, getting raw materials from a continuous screw at the back of the furnace adjacent to the exhaust air discharge. There are no provisions for heat recovery with unit melters.

In the "indirect" melting process, molten glass passes to a forehearth, where it is drawn off, sheared into globs, and formed into marbles by roll forming. The marbles are then stress relieved in annealing ovens, cooled, and conveyed to storage or to other plants for later use. In the "direct" glass fiber process, molten glass passes from the furnace into a refining unit, where bubbles and particles are removed by settling, and the melt is allowed to cool to the proper viscosity for the fiber forming operation.

Wool Glass Fiber Forming And Finishing - Wool fiberglass is produced for insulation and is formed into mats that are cut into batts. (Loose wool is primarily a waste product formed from mat trimming, although some is a primary product, and is only a small part of the total wool fiberglass produced. No specific emission data for loose wool production are available.) The insulation is used primarily in the construction industry and is produced to comply with ASTM C167-64, the "Standard Test Method for Thickness and Density of Blanket or Batt Type Thermal Insulating Material."²

Wool fiberglass insulation production lines usually consist of the following processes: (1) preparation of molten glass, (2) formation of fibers into a wool fiberglass mat, (3) curing the binder coated fiberglass mat, (4) cooling the mat, and (5) backing, cutting and packaging the insulation. Fiberglass plants contain various sizes, types, and numbers of production lines, although a typical plant has three lines. Backing (application of a flat flexible material, usually paper, glued to the mat), cutting and packaging operations are not significant sources of emissions to the atmosphere.

The trimmed edge waste from the mat and the fibrous dust generated during the cutting and packaging operations are collected by a cyclone and are either transported to a hammer mill to be chopped into blown wool (loose insulation) and bulk packaged or recycled to the forming section and blended with newly forming product.

During the formation of fibers into a wool fiberglass mat (the process known as forming in the industry), glass fibers are made from molten glass, and a chemical binder is simultaneously sprayed on the fibers as they are created. The binder is a thermosetting resin that holds the glass fibers together. Although the binder composition varies with product type, typically the binder consists of a solution of phenol-formaldehyde resin, water, urea, lignin, silane and ammonia. Coloring agents may also be added to the binder. Two methods of creating fibers are used by the industry. In the rotary spin process, depicted in Figure 8.11-2, centrifugal force causes molten glass to flow through small holes in the wall of a rapidly rotating cylinder to create fibers that are broken into pieces by an air stream. This is the newer of the two processes and dominates the industry today. In the flame attenuation process, molten glass flows by gravity from a furnace through numerous small orifices to create threads that are then

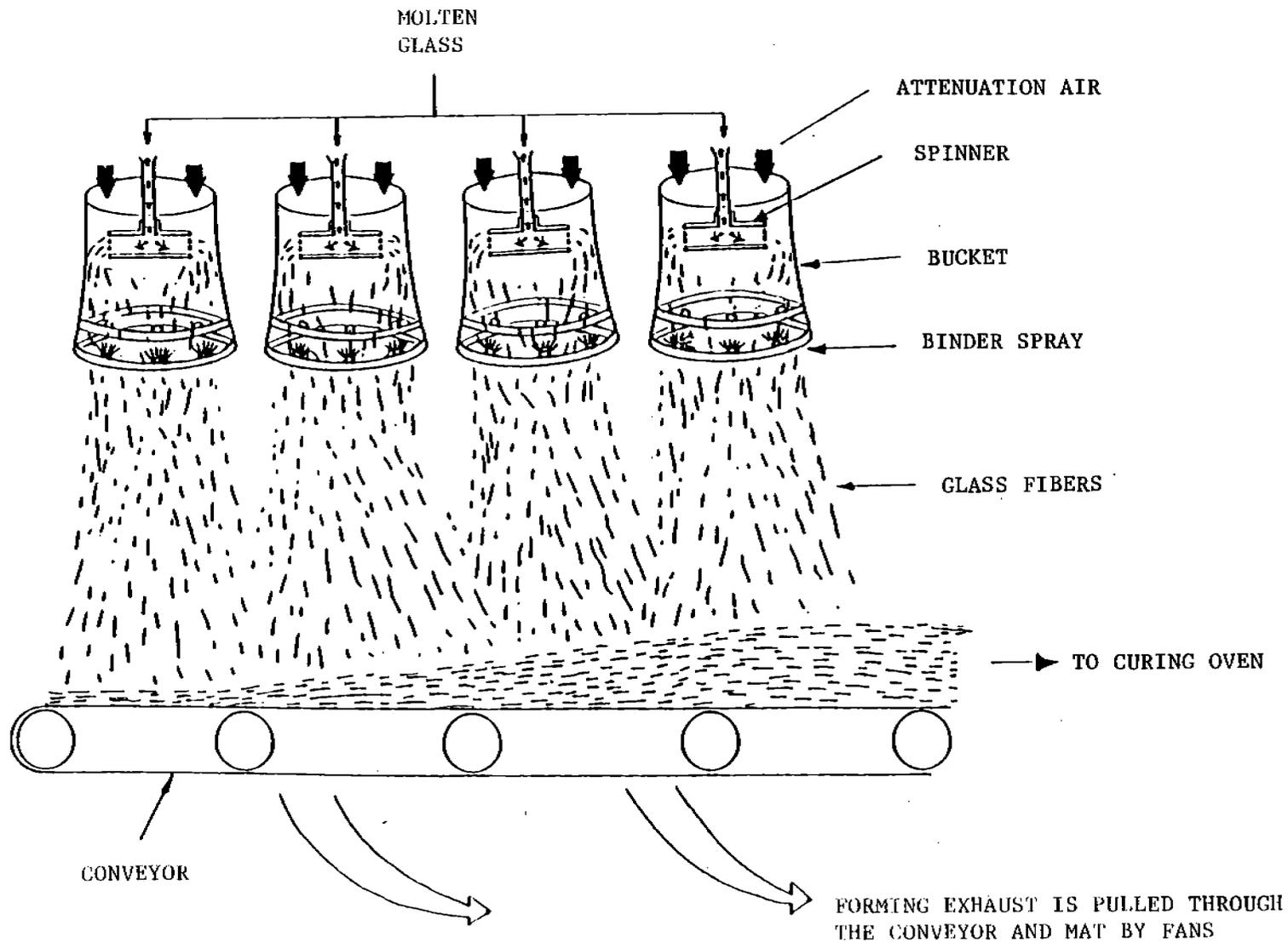


Figure 8.11-2. A typical rotary spin process.

attenuated (stretched to the point of breaking) by high velocity, hot air and/or a flame. After the glass fibers are created (by either process) and sprayed with the binder solution, they are collected by gravity on a conveyor belt in the form of a mat.

The conveyor carries the newly formed mat through a large oven for curing of the thermosetting binder and then through a cooling section where ambient air is drawn down through the mat. Figure 8.11-3 presents a schematic drawing of the curing and cooling sections. The cooled mat remains on the conveyor for trimming of the uneven edges. Then, if product specifications require it, a backing is applied with an adhesive to form a vapor barrier. The mat is then cut into batts of the desired dimensions and packaged.

Textile Glass Fiber Forming And Finishing - Molten glass from either the direct melting furnace or the indirect marble melting furnace is temperature regulated to a precise viscosity and delivered to forming stations. At the forming stations, the molten glass is forced through heated platinum bushings containing numerous very small orifices. The continuous fibers emerging from the orifices are drawn over a roller applicator which applies a coating of water soluble sizing and/or coupling agent. The coated fibers are gathered and wound into a spindle. The spindles of glass fibers are next conveyed to a drying oven, where moisture is removed from the sizing and coupling agents. The spindles are then sent to an oven to cure the coatings. The final fabrication includes twisting, chopping, weaving and packaging of the fiber.

8.11.2 Emissions And Controls

Emissions and controls for glass fiber manufacturing can be categorized by the three production phases with which they are associated. Emission factors for the glass fiber manufacturing industry are given in Tables 8.11-1 and 8.11-2.

Raw Materials Handling - The major emissions from the raw materials handling phase are fugitive dust and raw material particles generated at each of the material transfer points. Such a point would be where sand pours from a conveyor belt into a storage silo. The two major control techniques are wet or very moist handling and fabric filters. When fabric filters are used, the transfer points are enclosed, and air from the transfer area is continuously circulated through the fabric filters.

Glass Melting And Refining - The emissions from glass melting and refining include volatile organic compounds from the melt, raw material particles entrained in the furnace flue gas and, if furnaces are heated with fossil fuels, combustion products. The variation in emission rates among furnaces is attributable to varying operating temperature, raw material composition, fuels, and flue gas flow rates. Electric furnaces generally have the lowest emission rates, because of the lack of combustion products and of the lower temperature of the melt surface caused by bottom heating. Emission control for furnaces is primarily fabric filtration. Fabric filters are effective on particulates and SO_x and, to a lesser extent, on CO, NO_x and fluorides. Efficiency on these ^x compounds is attributable to both condens^xation on filterable particulates and chemical reaction with particulates

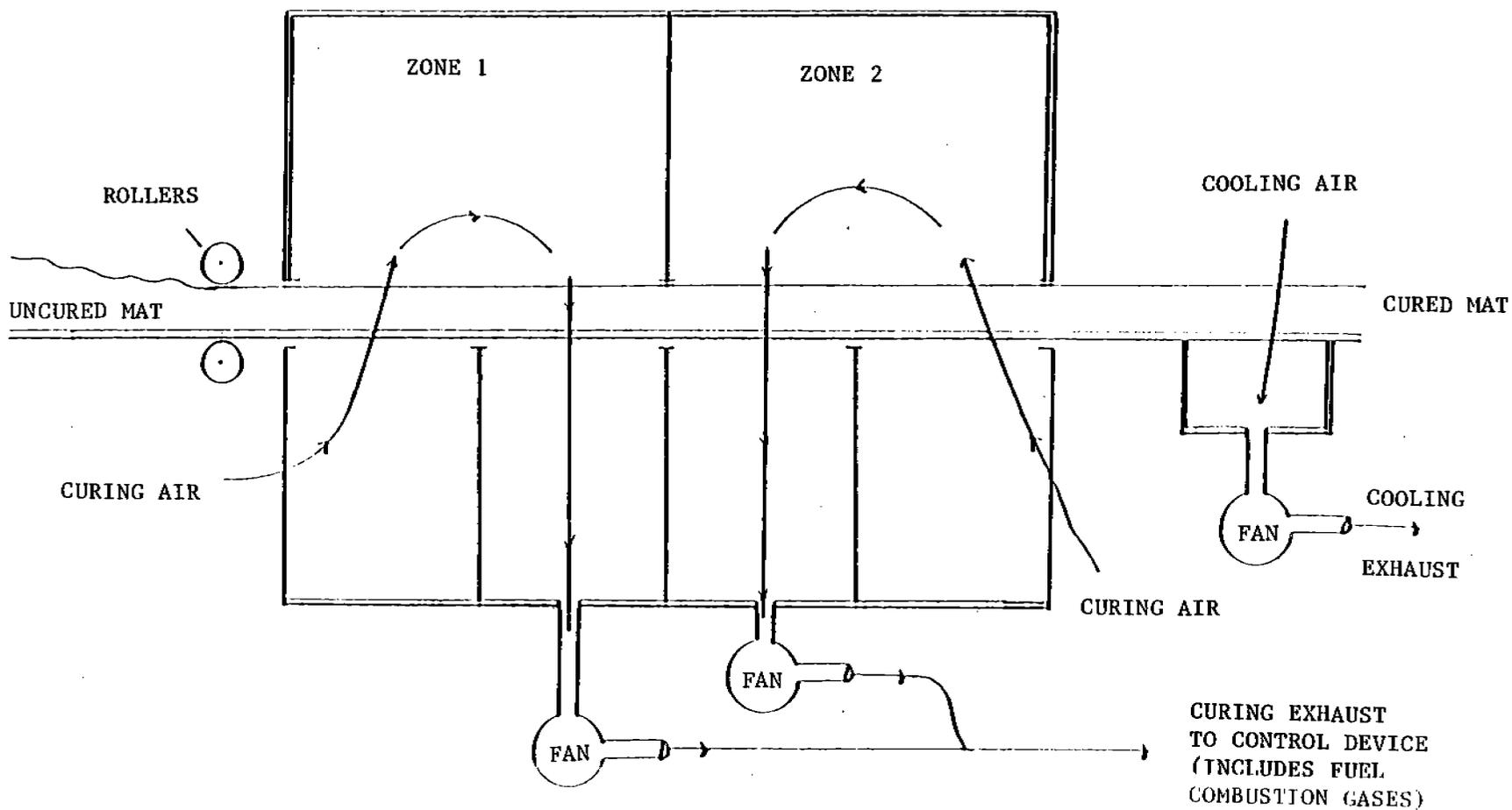


Figure 8.11-3. Side view of curing oven (indirect heating) and cooling section.

trapped on the filters. Reported fabric filter efficiencies on regenerative and recuperative wool furnaces are for particulates, 95+ percent; SO_x, 99+ percent; CO, 30 percent; and fluoride, 91 to 99 percent. Efficiencies on other furnaces are lower because of lower emission loading and pollutant characteristics.

Wool Fiber Forming And Finishing - Emissions generated during the manufacture of wool fiberglass insulation include solid particles of glass and binder resin, droplets of binder, and components of the binder that have vaporized. Glass particles may be entrained in the exhaust gas stream during forming, curing or cooling operations. Test data show that approximately 99 percent of the total emissions from the production line is emitted from the forming and curing sections. Even though cooling emissions are negligible at some plants, cooling emissions at others may include fugitives from the curing section. This commingling of emissions occurs because fugitive emissions from the open terminal end of the curing oven may be induced into the cooling exhaust ductwork and be discharged into the atmosphere. Solid particles of resin may be entrained in the gas stream in either the curing or cooling sections. Droplets of organic binder may be entrained in the gas stream in the forming section or may be a result of condensation of gaseous pollutants as the gas stream is cooled. Some of the liquid binder used in the forming section is vaporized by the elevated temperatures in the forming and curing processes. Much of the vaporized material will condense when the gas stream cools in the ductwork or in the emission control device.

Particulate matter is the principal pollutant that has been identified and measured at wool fiberglass insulation manufacturing facilities. It was known that some fraction of the particulate emissions results from condensation of organic compounds used in the binder. Therefore, in evaluating emissions and control device performance for this source, a sampling method, EPA Reference Method 5E, was used that permitted collection and measurement of both solid particles and condensed particulate material.³

Tests were performed during the production of R-11 building insulation, R-19 building insulation, ductboard and heavy density insulation.⁴ These products, which account for 91 percent of industry production, had densities ranging from 9.1 to 12.3 kilograms per cubic meter (kg/m³) for R-11, 8.2 to 9.3 kg/m³ for R-19, and 54.5 to 65.7 kg/m³ for ductboard. The heavy density insulation had a density of 118.5 kg/m³. (The remaining 9 percent of industry wool fiberglass production is a variety of specialty products for which qualitative and quantitative information is not available.) The loss on ignition (LOI) of the product is a measure of the amount of binder present. The LOI values ranged from 3.9 to 6.5 percent, 4.5 to 4.6 percent, and 14.7 to 17.3 percent, respectively. The LOI for heavy density is 10.6 percent. A production line may be used to manufacture more than one of these product types because the processes involved do not differ. Although the data base did not show sufficient differences in mass emission levels to establish separate emission standards for each product, the uncontrolled emission factors are sufficiently different to warrant their segregation for AP-42.

The level of emissions control found in the wool fiberglass insulation manufacturing industry ranges from uncontrolled to control of forming, curing

TABLE 8.11-1. EMISSION FACTORS FOR GLASS FIBER MANUFACTURING WITHOUT CONTROLS^a

EMISSION FACTOR RATING: B

	Particulates		SO _x		CO		NO _x		VOC ^b		Fluorides	
	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg
Unloading and conveying ^c	3.0	1.5	d	d	d	d	d	d	d	d	d	d
Storage bins ^c	0.2	0.1	d	d	d	d	d	d	d	d	d	d
Mixing and weighing ^c	0.6	0.3	d	d	d	d	d	d	d	d	d	d
Crushing and batch charging ^c	Neg	Neg	d	d	d	d	d	d	d	d	d	d
Glass furnace - wool												
Electric	0.5	0.25	0.04	0.02	0.05	0.025	0.27	0.14	e	e	0.002	0.001
Gas-regenerative	22	11	10	5	0.25	0.13	5	2.5	e	e	0.12	0.06
Gas-recuperative	25-30	13-15	10	5	0.25	0.13	1.7	0.85	e	e	0.11	0.06
Gas-unit melter	9	4.5	0.6	0.3	0.25	0.13	0.3	0.15	e	e	0.12	0.06
Glass furnace - textile												
Recuperative	2	1	3	1.5	0.5	0.25	20	10	d	d	2	1
Regenerative	16	8	30	15	1	0.5	20	10	d	d	2	1
Unit melter	6	3	e	e	0.9	0.45	20	10	d	d	2	1
Forming - wool												
Flame attenuation	2	1	d	d	d	d	d	d	0.3	0.15	e	e
Forming - textile	1	0.5	d	d	d	d	d	d	Neg	Neg	d	d
Oven curing - wool												
Flame attenuation	6	3	e	e	3.5	1.8	2	1	7	3.5	e	e
Oven curing and cooling - textile	1.2	0.6	d	d	1.5	0.75	2.6	1.3	Neg	Neg	d	d

^a Expressed as units per unit weight of raw material processed. Neg = negligible.^b Includes primarily phenols and aldehydes, and to a lesser degree, methane.^c Reference 1.^d Not applicable.^e Data are available.

and cooling emissions from a line. The exhausts from these process operations may be controlled separately or in combination. Control technologies currently used by the industry include wet ESPs, low and high pressure drop wet scrubbers, low and high temperature thermal incinerators, high velocity air filters, and process modifications. These added control technologies are available to all firms in the industry, but the process modifications used in this industry are considered confidential. Wet ESPs are considered to be best demonstrated technology for the control of emissions from wool fiberglass insulation manufacturing lines.⁴ Therefore, it is expected that most new facilities will be controlled in this manner.

Textile Fiber Forming And Finishing - Emissions from the forming and finishing processes include glass fiber particles, resin particles, hydrocarbons (primarily phenols and aldehydes), and combustion products from dryers and ovens. Emissions are usually lower in the textile fiber glass process than in the wool fiberglass process because of lower turbulence in the forming step, roller application of coatings, and use of much less coating per ton of fiber produced.

TABLE 8.11-2. UNCONTROLLED EMISSION FACTORS FOR ROTARY SPIN WOOL GLASS FIBER MANUFACTURING^a

EMISSION FACTOR RATING: B

Products	Particulate			Organic compounds ^b		
	Front half	Back half	Total	Phenolics ^c	Phenol	Formaldehyde
R-19	17.81 (36.21)	4.25 (8.52)	22.36 (44.72)	3.21 (6.92)	0.96 (1.92)	0.75 (1.50)
R-11	19.61 (39.21)	3.19 (6.37)	22.79 (45.59)	6.21 (12.41)	0.92 (1.84)	1.23 (2.46)
Ductboard	27.72 (55.42)	8.55 (17.08)	36.26 (72.50)	10.66 (21.31)	3.84 (7.68)	1.80 (3.61)
Heavy density	4.91 (9.81)	1.16 (2.33)	6.07 (12.14)	0.88 (1.74)	0.53 (1.04)	0.43 (0.85)

^aReference 4. Expressed in kg/Mg (lb/ton) of finished product. Gas stream did not pass through any added primary control device (wet ESP, venturi scrubber, etc.).

^bIncluded in total particulate catch. These organics are collected as condensable particulate matter and do not necessarily represent the entire organics present in the exhaust gas stream.

^cIncludes phenol.

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8.19 CONSTRUCTION AGGREGATE PROCESSING

General¹⁻²

The construction aggregate industry covers a range of subclassifications of the nonmetallic minerals industry (see Section 8.23, Metallic Minerals Processing, for information on that similar activity). Many operations and processes are common to both groups, including mineral extraction from the earth, loading, unloading, conveying, crushing, screening, and loadout. Other operations are restricted to specific subcategories. These include wet and dry fine milling or grinding, air classification, drying, calcining, mixing, and bagging. The latter group of operations is not generally associated with the construction aggregate industry but can be conducted on the same raw materials used to produce aggregate. Two examples are processing of limestone and sandstone. Both substances can be used as construction materials and may be processed further for other uses at the same location. Limestone is a common source of construction aggregate, but it can be further milled and classified to produce agricultural limestone. Sandstone can be processed into construction sand and also can be wet and/or dry milled, dried, and air classified into industrial sand.

The construction aggregate industry can be categorized by source, mineral type or form, wet versus dry, washed or unwashed, and end uses, to name but a few. The industry is divided in this document into Section 8.19.1, Sand And Gravel Processing, and Section 8.19.2, Crushed Stone Processing. Sections on other categories of the industry will be published when data on these processes become available.

Uncontrolled construction aggregate processing can produce nuisance problems and can have an effect upon attainment of ambient particulate standards. However, the generally large particles produced often can be controlled readily. Some of the individual operations such as wet crushing and grinding, washing, screening, and dredging take place with "high" moisture (more than about 1.5 to 4.0 weight percent). Such wet processes do not generate appreciable particulate emissions.

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2. Review Emissions Data Base And Develop Emission Factors For The Construction Aggregate Industry, Engineering-Science, Inc., Arcadia, CA, September 1984.



8.19.1 SAND AND GRAVEL PROCESSING

8.19.1.1 Process Description¹⁻³

Deposits of sand and gravel, the consolidated granular materials resulting from the natural disintegration of rock or stone, are generally found in near-surface alluvial deposits and in subterranean and subaqueous beds. Sand and gravel are products of the weathering of rocks and unconsolidated or poorly consolidated materials and consist of siliceous and calcareous components. Such deposits are common throughout the country.

Depending upon the location of the deposit, the materials are excavated with power shovels, draglines, front end loaders, suction dredge pumps or other apparatus. In rare situations, light charge blasting is done to loosen the deposit. The materials are transported to the processing plant by suction pump, earth mover, barge, truck or other means. The processing of sand and gravel for a specific market involves the use of different combinations of washers, screens and classifiers to segregate particle sizes; crushers to reduce oversize material; and storage and loading facilities. Crushing operations, when used, are designed to reduce production of fines, which often must be removed by washing. Therefore, crusher characteristics, size reduction ratios and throughput, among other factors, are selected to obtain the desired product size distribution.

In many sand and gravel plants, a substantial portion of the initial feed bypasses any crushing operations. Some plants do no crushing at all. After initial screening, material is conveyed to a portion of the plant called the wet processing section, where wet screening and silt removal are conducted to produce washed sand and gravel. Negligible air emissions are expected from the wet portions of a sand and gravel plant.

Industrial sand processing is similar to that of construction sand, insofar as the initial stages of crushing and screening are concerned. Industrial sand has a high (90 to 99 percent) quartz or silica content and is frequently obtained from quartz rich deposits of sand or sandstone. At some plants, after initial crushing and screening, a portion of the sand may be diverted to construction sand use. Industrial sand processes not associated with construction sand include wet milling, scrubbing, desliming, flotation, drying, air classification and cracking of sand grains to form very fine sand products.

8.19.1.2 Emissions and Controls¹

Dust emissions can occur from many operations at sand and gravel processing plants, such as conveying, screening, crushing, and storing operations. Generally, these materials are wet or moist when handled, and process emissions are often negligible. A substantial portion of these emissions may consist of heavy particles that settle out within the plant. Emission factors (for process or fugitive dust sources) from sand and gravel processing plants are shown in Table 8.19.1-1. (If processing is dry, expected emissions could be similar to those given in Section 8.19.2, Crushed Stone Processing).

Emission factors for crushing wet materials can be applied directly or on a dry basis, with a control efficiency credit being given for use of wet

materials (defined as 1.5 to 4.0 percent moisture content or greater) or wet suppression. The latter approach is more consistent with current practice.

The single valued fugitive dust emission factors given in Table 8.19.1-1 may be used for an approximation when no other information exists. Empirically derived emission factor equations presented in Section 11.2 of this document are preferred and should be used when possible. Each of those equations has been developed for a single source operation or dust generating mechanism which crosses industry lines, such as vehicle traffic on unpaved roads. The predictive equation explains much of the observed variance in measured emission factors by relating emissions to the differing source variables. These variables may be grouped as (1) measures of source activity or expended energy (e. g., feed rate, or speed and weight of a vehicle traveling on an unpaved road), (2) properties of the material being disturbed (e. g., moisture content, or content of suspendable fines in the material) and (3) climate (e. g., number of precipitation free days per year, when emissions tend to a maximum).

Because predictive equations allow for emission factor adjustment to specific conditions, they should be used instead of the factors given in Table 8.19.1-1 whenever emission estimates are needed for sources in a specific sand and gravel processing facility. However, the generally higher quality ratings assigned to these equations are applicable only if (1) reliable values of correction parameters have been determined for the specific sources of interest, and (2) the correction parameter values lie within the ranges found in developing the equations. Section 11.2 lists measured properties of aggregate materials used in operations similar to the sand and gravel industry, and these properties can be used to approximate correction parameter values for use in the predictive emission factor equations, in the event that site specific values are not available. Use of mean correction parameter values from Chapter 11 reduces the quality ratings of the emission factor equations by at least one level.

Since emissions from sand and gravel operations usually are in the form of fugitive dust, control techniques applicable to fugitive dust sources are appropriate. Some successful control techniques used for haul roads are application of dust suppressants, paving, route modifications, soil stabilization, etc.; for conveyors, covering and wet suppression; for storage piles, wet dust suppression, windbreaks, enclosure and soil stabilizers; and for conveyor and batch transfer points (loading and unloading, etc.), wet suppression and various methods to reduce freefall distances (e. g., telescopic chutes, stone ladders, and hinged boom stacker conveyors); for screening and other size classification, covering and wet suppression.

Wet suppression techniques include application of water, chemicals and/or foam, usually at crusher or conveyor feed and/or discharge points. Such spray systems at transfer points and on material handling operations have been estimated to reduce emissions 70 to 95 percent.⁷ Spray systems can also reduce loading and wind erosion emissions from storage piles of various materials 80 to 90 percent.⁸ Control efficiencies depend upon local climatic conditions, source properties and duration of control effectiveness. Wet suppression has a carryover effect downstream of the point of application of water or other wetting agents, as long as the surface moisture content is high enough to cause the fines to adhere to the larger rock particles.

TABLE 8.19.1-1. UNCONTROLLED PARTICULATE EMISSION FACTORS
FOR SAND AND GRAVEL PROCESSING PLANTS^a

Uncontrolled Operation	Emissions by Particle Size Range (aerodynamic diameter) ^b			Units	Emission Factor Rating
	Total Particulate	TSP (< 30 μm)	PM ₁₀ (< 10 μm)		
Process Sources ^c Primary or secondary crushing (wet)	NA	0.009 (0.018)	NA	kg/Mg (lb/ton)	D
Open Dust Sources ^c Screening ^d Flat screens (dry product)	NA	0.08 (0.16)	0.06 (0.12)	kg/Mg (lb/ton)	C
Continuous drop ^c Transfer station Pile formation - stacker	0.014 (0.029)	NA	NA	kg/Mg (lb/ton)	E
	NA	0.065 (0.13)	0.03 (0.06) ^e	kg/Mg (lb/ton)	E
Batch drop ^c Bulk loading	0.12 (0.024)	0.028 (0.056) ^f	0.0012 (0.0024) ^f	kg/Mg (lb/ton)	E
Active storage piles ^g Active day	NA	14.8 (13.2)	7.1 (6.3) ^e	kg/hectare/day ^h (lb/acre/day)	D
	NA	3.9 (3.5)	1.9 (1.7) ^e	kg/hectare/day ^h (lb/acre/day)	D
Unpaved haul roads Wet materials	i	i	i		D

^aNA = not available. TSP = total suspended particulate. Predictive emission factor equations, which generally provide more accurate estimates of emissions under specific conditions, are presented in Chapter 11. Factors for open dust sources are not necessarily representative of the entire industry or of a "typical" situation.

^bTotal particulate is airborne particles of all sizes in the source plume. TSP is what is measured by a standard high volume sampler (see Section 11.2).

^cReferences 5-9.

^dReferences 4-5. For completely wet operations, emissions are likely to be negligible.

^eExtrapolation of data, using k factors for appropriate operation from Chapter 11.

^fFor physical, not aerodynamic, diameter.

^gReference 6. Includes the following distinct source operations in the storage cycle: (1) loading of aggregate onto storage piles (batch or continuous drop operations), (2) equipment traffic in storage areas, (3) wind erosion of pile (batch or continuous drop operations). Assumes 8 to 12 hours of activity/24 hours.

^hkg/hectare (lb/acre) of storage/day (includes areas among piles).

ⁱSee Section 11.2 for empirical equations.

References for Section 8.19.1

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8.19.2 CRUSHED STONE PROCESSING

8.19.2.1 Process Description¹

Major rock types processed by the rock and crushed stone industry include limestone, dolomite, granite, traprock, sandstone, quartz and quartzite. Minor types include calcareous marl, marble, shell and slate. Industry classifications vary considerably and, in many cases, do not reflect actual geological definitions.

Rock and crushed stone products generally are loosened by drilling and blasting, then are loaded by power shovel or front end loader and transported by heavy earth moving equipment. Techniques used for extraction vary with the nature and location of the deposit. Further processing may include crushing, screening, size classification, material handling, and storage operations. All of these processes can be significant sources of dust emissions if uncontrolled. Some processing operations also include washing, depending on rock type and desired product.

Quarried stone normally is delivered to the processing plant by truck and is dumped into a hoppers feeder, usually a vibrating grizzly type, or onto screens, as illustrated in Figure 8.19.2-1. These screens separate or scalp large boulders from finer rocks that do not require primary crushing, thus reducing the load to the primary crusher. Jaw, or gyratory, crushers are usually used for initial reduction. The crusher product, normally 7.5 to 30 centimeters (3 to 12 inches) in diameter, and the grizzly throughs (undersize material) are discharged onto a belt conveyor and usually are transported either to secondary screens and crushers or to a surge pile for temporary storage.

Further screening generally separates the process flow into either two or three fractions (oversize, undersize and throughs) ahead of the secondary crusher. The oversize is discharged to the secondary crusher for further reduction, and the undersize usually bypasses the secondary crusher. The throughs sometimes are separated, because they contain unwanted fines, and are stockpiled as crusher run material. Gyratory crushers or cone crushers are commonly used for secondary crushing, although impact crushers are sometimes found.

The product of the secondary crushing stage, usually 2.5 centimeters (1 inch) diameter or less, is transported to secondary screens for further sizing. Oversize material is sent back for recrushing. Depending on rock type and desired product, tertiary crushing or grinding may be necessary, usually using cone crushers or hammermills. (Rod mills, ball mills and hammer mills normally are used in milling operations, which are not considered a part of the construction aggregate industry.) The product from tertiary crushing may be conveyed to a classifier, such as a dry vibrating screen system, or to an air separator. Any oversize is returned to the tertiary crusher for further reduction. At this point, end products of the desired grade are conveyed or trucked directly to finished product bins or to open area stockpiles.

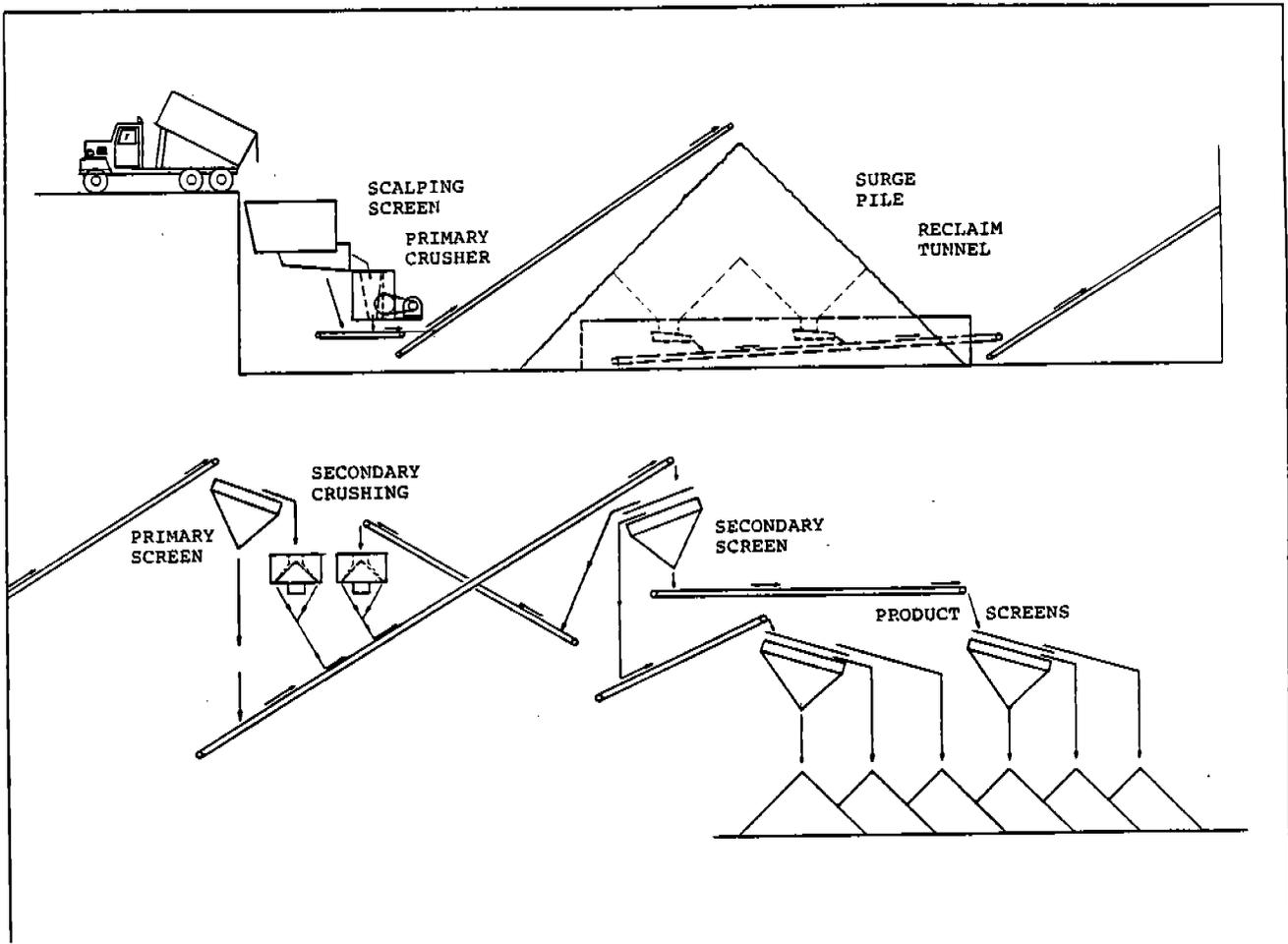


FIGURE 8.19.2-1. TYPICAL STONE PROCESSING PLANT

In certain cases, stone washing is required to meet particular end product specifications or demands, as with concrete aggregate processing. Crushed and broken stone normally are not milled but are screened and shipped to the consumer after secondary or tertiary crushing.

8.19.2.2 Emissions and Controls¹⁻³

Dust emissions occur from many operations in stone quarrying and processing. A substantial portion of these emissions consists of heavy particles that may settle out within the plant. As in other operations, crushed stone emission sources may be categorized as either process sources or fugitive dust sources. Process sources include those for which emissions are amenable to capture and subsequent control. Fugitive dust sources generally involve the reentrainment of settled dust by wind or machine movement. Factors affecting emissions from either source category include the type, quantity and surface moisture content of the stone processed; the type of equipment and operating practices employed; and topographical and climatic factors.

Of geographic and seasonal factors, the primary variables affecting uncontrolled particulate emissions are wind and material moisture content. Wind parameters vary with geographical location, season and weather. It can be expected that the level of emissions from unenclosed sources (principally fugitive dust sources) will be greater during periods of high winds. The material moisture content also varies with geographic location, season and weather. Therefore, the levels of uncontrolled emissions from both process emission sources and fugitive dust sources generally will be greater in arid regions of the country than in temperate ones, and greater during the summer months because of a higher evaporation rate.

The moisture content of the material processed can have a substantial effect on uncontrolled emissions. This is especially evident during mining, initial material handling, and initial plant process operations such as primary crushing. Surface wetness causes fine particles to agglomerate on, or to adhere to, the faces of larger stones, with a resulting dust suppression effect. However, as new fine particles are created by crushing and attrition, and as the moisture content is reduced by evaporation, this suppressive effect diminishes and may disappear. Depending on the geographic and climatic conditions, the moisture content of mined rock may range from nearly zero to several percent. Since moisture content is usually expressed on a basis of overall weight percent, the actual moisture amount per unit area will vary with the size of the rock being handled. On a constant mass fraction basis, the per unit area moisture content varies inversely with the diameter of the rock. Therefore, the suppressive effect of the moisture depends on both the absolute mass water content and the size of the rock product. Typically, a wet material will contain 1.5 to 4 percent water or more.

There are a large number of material, equipment and operating factors which can influence emissions from crushing. These include: (1) rock type, (2) feed size and distribution, (3) moisture content, (4) throughput rate, (5) crusher type, (6) size reduction ratio, and (7) fines content. Insufficient data are available to present a matrix of rock crushing emission factors detailing the above classifications and variables. Data available from which to prepare emission factors also vary considerably, for both extractive testing and plume profiling. Emission factors from extractive testing are generally

higher than those based upon plume profiling tests, but they have a greater degree of reliability. Some test data for primary crushing indicate higher emissions than from secondary crushing, although factors affecting emission rates and visual observations suggest that the secondary crushing emission factor, on a throughput basis, should be higher. Table 8.19.2-1 shows single factors for either primary or secondary crushing reflecting a combined data base. An emission factor for tertiary crushing is given, but it is based on extremely limited data. All factors are rated low because of the limited and highly variable data base.

TABLE 8.19.2-1. UNCONTROLLED PARTICULATE EMISSION FACTORS FOR CRUSHING OPERATIONS^a

Type of Crushing ^b	Particulate Matter		Emission Factor Rating
	< 30 μ m kg/Mg (lb/ton)	< 10 μ m kg/Mg (lb/ton)	
Primary or secondary Dry material	0.14 (0.28)	0.0085 (0.017)	D
Wet material ^c	0.009 (0.018)	-	D
Tertiary, dry material ^d	0.93 (1.85)	-	E

^aBased on actual feed rate of raw material entering the particular operation. Emissions will vary by rock type, but data available are insufficient to characterize these phenomena. Dash = no data.

^bReferences 4-5. Factors are uncontrolled. Typical control efficiencies: cyclone, 70 - 80%; fabric filter, 99%; wet spray systems, 70 - 90%.

^cReferences 5-6. Refers to crushing of rock either naturally wet or after moistened to 1.5 to 4 weight % by use of wet suppression techniques.

^dRange of values used to calculate emission factor was 0.0008 - 1.38 kg/Mg.

There are no screening emission factors presented in this Section. However, the screening emission factors given in Section 8.19.1, Sand and Gravel Processing, should be similar to those expected from screening crushed rock. Milling of fines is also not included in this Section as this operation is normally associated with non construction aggregate end uses and will be covered elsewhere in the future when information is adequate.

Open dust source (fugitive dust) emission factors for stone quarrying and processing are presented in Table 8.19.2-2. These factors have been determined through tests at various quarries and processing plants.⁶⁻⁷ The single valued open dust emission factors given in Table 8.19.2-2 may be used when no other information exists. Empirically derived emission factor equations presented in Section 11.2 of this document are preferred and should be used when possible. Because these predictive equations allow the adjustment of emission factors for

TABLE 8.19.2-2. UNCONTROLLED PARTICULATE EMISSION FACTORS FOR OPEN DUST SOURCES AT CRUSHED STONE PLANTS

Operation	Material	Emissions by Particle Size Range (aerodynamic diameter) ^a			Emission Factor Rating
		TSP	PM ₁₀	Units ^b	
		< 30 μm	< 10 μm		
Quarrying	Unfractured Stone ^c	0.4 (0.0008)	0.04 (0.0001)	g/Mg (lb/ton)	E
Wet drilling					
Blasting	Unfractured Stone ^c	$\frac{961(A)^{0.8}}{(D)^{1.8} \times (M)^{1.9}}$ ^d	0.2 x TSP ^d	lb/blast	D
Batch Drop	Fractured Stone ^c	0.17 (0.0003)	0.008 (0.00002)	g/Mg (lb/ton)	D
Truck unloading					
Truck loading	Crushed Stone ^e	0.17 (0.0003)	0.05 (0.0001)	g/Mg (lb/ton)	E
conveyor	Crushed Stone ^f	29.0 (0.06)	NA	g/Mg (lb/ton)	E
Front end loader					
Conveying	Crushed Stone ^c	1.7 (0.0034)	0.11 (0.0002)	g/Mg (lb/ton)	E
Tunnel Belt					
Unpaved haul roads		g	g		

^aTotal suspended particulate (TSP) is that measured by a standard high volume sampler (See Section 11.2). Use of empirical equations in Chapter 11 is preferred to single value factors in this Table. Factors in this Table are provided for convenience in quick approximations and/or for occasions when equation variables can not be reasonably estimated. NA = not available.

^bExpressed as g/Mg (lb/ton) of material through primary crusher, except for front end loading, g/Mg (lb/ton) of material transferred, and blasting which is kg/blast.

^cReference 2.

^dWhere A = Area blasted in ft²; D = Depth of blast in ft; and M = Moisture content; (Adapted from Table 8.24-2. Use moisture content of 1 - 2% and depth equal to depth of drill or depth from blast to vertical face, whichever is less.) Multiply TSP value by 0.2 to estimate quantity of particulate < 10 μm (PM₁₀).

^eReference 3.

^fReference 6.

^gSee Section 11.2 for empirical equations.

specific source conditions, these equations should be used instead of those in Table 8.19.2-2, whenever emission estimates applicable to specific stone quarrying and processing facility sources are needed. Chapter 11.2 provides measured properties of crushed limestone, as required for use in the predictive emission factor equations.

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SECTION 8.20

This Section is reserved for future use.



11.2.1 UNPAVED ROADS

11.2.1.1 General

Dust plumes trailing behind vehicles traveling on unpaved roads are a familiar sight in rural areas of the United States. When a vehicle travels an unpaved road, the force of the wheels on the road surface causes pulverization of surface material. Particles are lifted and dropped from the rolling wheels, and the road surface is exposed to strong air currents in turbulent shear with the surface. The turbulent wake behind the vehicle continues to act on the road surface after the vehicle has passed.

11.2.1.2 Emissions And Correction Parameters

The quantity of dust emissions from a given segment of unpaved road varies linearly with the volume of traffic. Also, field investigations have shown that emissions depend on correction parameters (average vehicle speed, average vehicle weight, average number of wheels per vehicle, road surface texture and road surface moisture) that characterize the condition of a particular road and the associated vehicle traffic.¹⁻⁴

Dust emissions from unpaved roads have been found to vary in direct proportion to the fraction of silt (particles smaller than 75 micrometers in diameter) in the road surface materials.¹ The silt fraction is determined by measuring the proportion of loose dry surface dust that passes a 200 mesh screen, using the ASTM-C-136 method. Table 11.2.1-1 summarizes measured silt values for industrial and rural unpaved roads.

The silt content of a rural dirt road will vary with location, and it should be measured. As a conservative approximation, the silt content of the parent soil in the area can be used. However, tests show that road silt content is normally lower than in the surrounding parent soil, because the fines are continually removed by the vehicle traffic, leaving a higher percentage of coarse particles.

Unpaved roads have a hard nonporous surface that usually dries quickly after a rainfall. The temporary reduction in emissions because of precipitation may be accounted for by not considering emissions on "wet" days (more than 0.254 millimeters [0.01 inches] of precipitation).

The following empirical expression may be used to estimate the quantity of size specific particulate emissions from an unpaved road, per vehicle kilometer traveled (VKT) or vehicle mile traveled (VMT), with a rating of A:

$$E = k(1.7) \left(\frac{s}{12} \right) \left(\frac{S}{48} \right) \left(\frac{W}{2.7} \right)^{0.7} \left(\frac{w}{4} \right)^{0.5} \left(\frac{365-p}{365} \right) \quad (\text{kg/VKT}) \quad (1)$$

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

TABLE 11.2.1-1. TYPICAL SILT CONTENT VALUES OF SURFACE MATERIALS
ON INDUSTRIAL AND RURAL UNPAVED ROADS^a

Industry	Road Use Or Surface Material	Plant Sites	Test Samples	Silt (% w/w)	
				Range	Mean
Copper smelting	Plant road	1	3	[15.9 - 19.1]	[17.0]
Iron and steel production	Plant road	9	20	4.0 - 16.0	8.0
Sand and gravel processing	Plant road	1	3	[4.1 - 6.0]	[4.8]
Stone quarrying and processing	Plant road	1	5	[10.5 - 15.6]	[14.1]
Taconite mining and processing	Haul road	1	12	[3.7 - 9.7]	[5.8]
	Service road	1	8	[2.4 - 7.1]	[4.3]
Western surface coal mining	Access road	2	2	4.9 - 5.3	5.1
	Haul road	3	21	2.8 - 18	8.4
	Scraper road	3	10	7.2 - 25	17
	Haul road (freshly graded)	2	5	18 - 29	24
Rural roads	Gravel	1	1	NA	[5.0]
	Dirt	2	5	5.8 - 68	28.5
	Crushed limestone	2	8	7.7 - 13	9.6

^aReferences 4 - 11. Brackets indicate silt values based on samples from only one plant site.
NA = Not available.

where: E = emission factor
 k = particle size multiplier (dimensionless)
 s = silt content of road surface material (%)
 S = mean vehicle speed, km/hr (mph)
 W = mean vehicle weight, Mg (ton)
 w = mean number of wheels
 p = number of days with at least 0.254 mm
 (0.01 in.) of precipitation per year

The particle size multiplier, k, in Equation 1 varies with aerodynamic particle size range as follows:

Aerodynamic Particle Size Multiplier For Equation 1

$\leq 30 \mu\text{m}$	$\leq 15 \mu\text{m}$	$\leq 10 \mu\text{m}$	$\leq 5 \mu\text{m}$	$\leq 2.5 \mu\text{m}$
0.80	0.50	0.36	0.20	0.095

The number of wet days per year, p, for the geographical area of interest should be determined from local climatic data. Figure 11.2.1-1 gives the geographical distribution of the mean annual number of wet days per year in the United States.

Equation 1 retains the assigned quality rating if applied within the ranges of source conditions that were tested in developing the equation, as follows:

RANGES OF SOURCE CONDITIONS FOR EQUATION 1

Equation	Road silt content (%, w/w)	Mean vehicle weight		Mean vehicle speed		Mean no. of wheels
		Mg	ton	km/hr	mph	
1	4.3 - 20	2.7 - 142	3 - 157	21 - 64	13 - 40	4 - 13

Also, to retain the quality rating of the equation applied to a specific unpaved road, it is necessary that reliable correction parameter values for the specific road in question be determined. The field and laboratory procedures for determining road surface silt content are given in Reference 4. In the event that site specific values for correction parameters cannot be obtained, the appropriate mean values from Table 11.2.1-1 may be used, but the quality rating of the equation is reduced to B.

Equation 1 was developed for calculation of annual average emissions, and thus, is to be multiplied by annual vehicle distance traveled (VDT). Annual average values for each of the correction parameters are to be substituted into

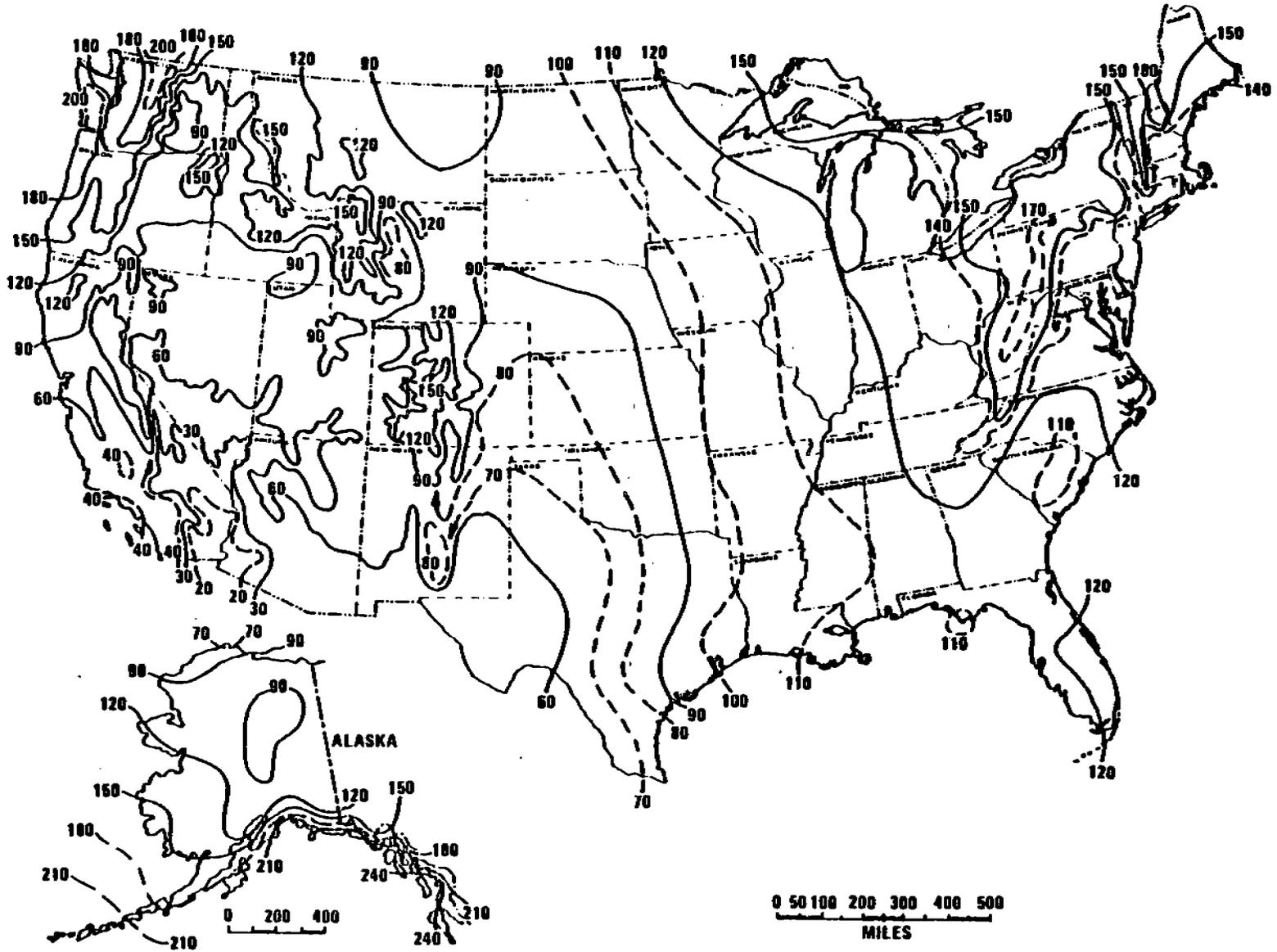


Figure 11.2.1-1. Mean number of days with 0.01 inch or more of precipitation in United States.¹⁰

the equation. Worst case emissions, corresponding to dry road conditions, may be calculated by setting $p = 0$ in the equation (which is equivalent to dropping the last term from the equation). A separate set of nonclimatic correction parameters and a higher than normal VDT value may also be justified for the worst case averaging period (usually 24 hours). Similarly, to calculate emissions for a 91 day season of the year using Equation 1, replace the term $(365-p)/365$ with the term $(91-p)/91$, and set p equal to the number of wet days in the 91 day period. Also, use appropriate seasonal values for the nonclimatic correction parameters and for VDT.

11.2.1.3 Control Methods

Common control techniques for unpaved roads are paving, surface treating with penetration chemicals, working into the roadbed of chemical stabilization chemicals, watering, and traffic control regulations. Chemical stabilizers work either by binding the surface material or by enhancing moisture retention. Paving, as a control technique, is often not economically practical. Surface chemical treatment and watering can be accomplished with moderate to low costs, but frequent retreatments are required. Traffic controls, such as speed limits and traffic volume restrictions, provide moderate emission reductions but may be difficult to enforce. The control efficiency obtained by speed reduction can be calculated using the predictive emission factor equation given above.

The control efficiencies achievable by paving can be estimated by comparing emission factors for unpaved and paved road conditions, relative to airborne particle size range of interest. The predictive emission factor equation for paved roads, given in Section 11.2.6, requires estimation of the silt loading on the traveled portion of the paved surface, which in turn depends on whether the pavement is periodically cleaned. Unless curbing is to be installed, the effects of vehicle excursion onto shoulders (berms) also must be taken into account in estimating control efficiency.

The control efficiencies afforded by the periodic use of road stabilization chemicals are much more difficult to estimate. The application parameters which determine control efficiency include dilution ratio, application intensity (mass of diluted chemical per road area) and application frequency. Between applications, the control efficiency is usually found to decay at a rate which is proportional to the traffic count. Therefore, for a specific chemical application program, the average efficiency is inversely proportional to the average daily traffic count. Other factors that affect the performance of chemical stabilizers include vehicle characteristics (e. g., average weight) and road characteristics (e. g., bearing strength).

Water acts as a road dust suppressant by forming cohesive moisture films among the discrete grains of road surface material. The average moisture level in the road surface material depends on the moisture added by watering and natural precipitation and on the moisture removed by evaporation. The natural evaporative forces, which vary with geographic location, are enhanced by the movement of traffic over the road surface. Watering, because of the frequency of treatments required, is generally not feasible for public roads and is used effectively only where water and watering equipment are available and where roads are confined to a single site, such as a construction location.

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11.2.5 PAVED URBAN ROADS

11.2.5.1 General

Various field studies have indicated that dust emissions from paved street are a major component of the material collected by high volume samplers. Reentrained traffic dust has been found to consist primarily of mineral matter similar to common sand and soil, mostly tracked or deposited onto the roadway by vehicle traffic itself. Other particulate matter is emitted directly by the vehicles from, for example, engine exhaust, wear of bearings and brake linings, and abrasion of tires against the road surface. Some of these direct emissions may settle to the street surface, subsequently to be reentrained. Appreciable emissions from paved streets are added by wind erosion when the wind velocity exceeds a threshold value of about 20 kilometers per hour (13 miles per hour).² Figure 11.2.5-1 illustrates particulate transfer processes occurring on urban streets.

11.2.5.2 Emission Factors And Correction Parameters

Dust emission rates may vary according to a number of factors. The most important are thought to be traffic volume and the quantity and particle size of loose surface material on the street. On a normal paved street, an equilibrium is reached whereby the accumulated street deposits are maintained at a relatively constant level. On average, vehicle carryout from unpaved areas may be the largest single source of street deposit. Accidental spills, street cleaning and rainfall are activities that disrupt the street loading equilibrium, usually for a relatively short duration.

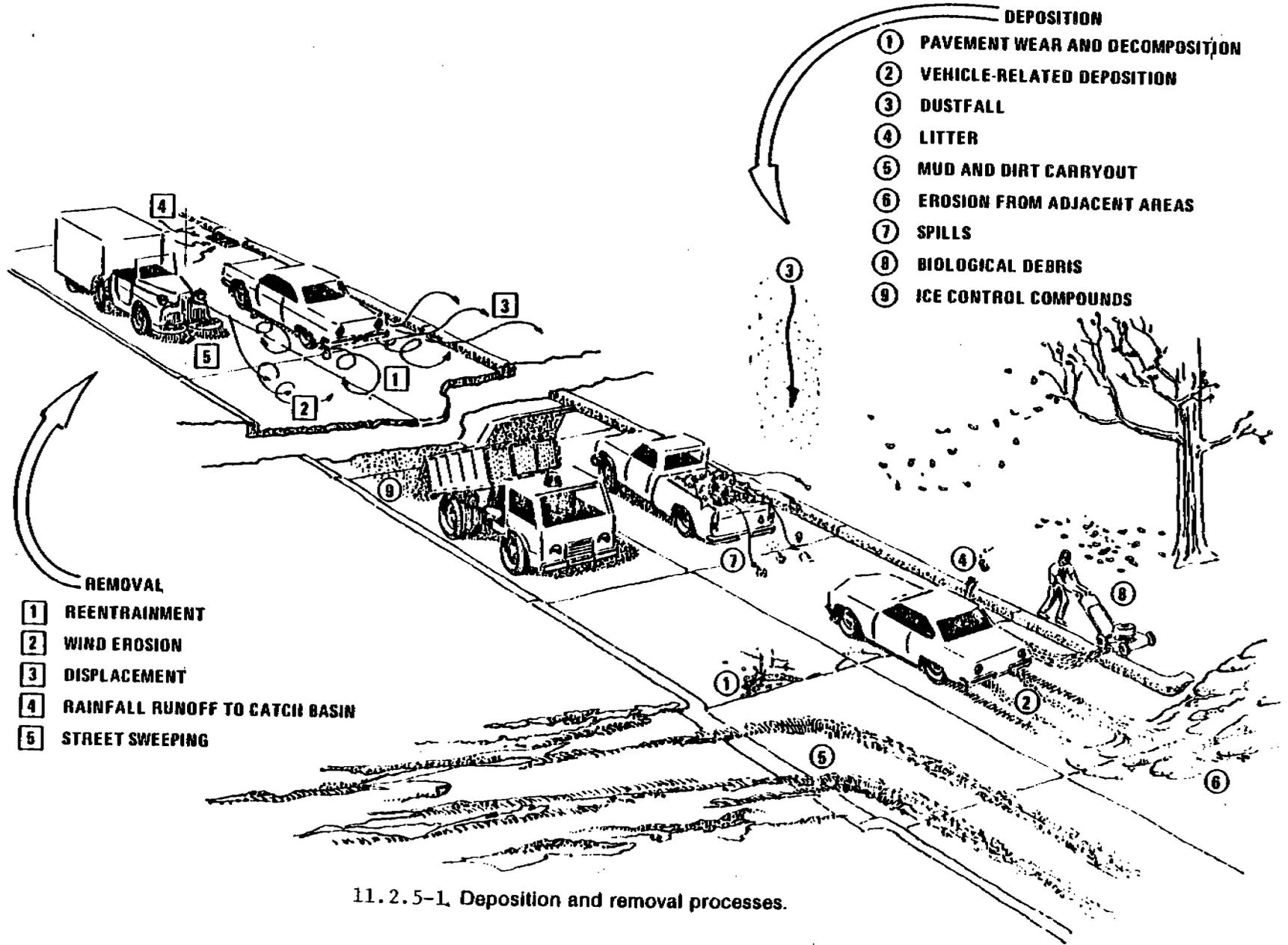
The lead content of fuels also becomes a part of reentrained dust from vehicle traffic. Studies have found that, for the 1975-76 sampling period, the lead emission factor for this source was approximately 0.03 grams per vehicle mile traveled (VMT). With the reduction of lead in gasoline and the use of catalyst equipped vehicles, the lead factor for reentrained dust was expected to drop below 0.01 grams per mile by 1980.³

The quantity of dust emissions of vehicle traffic on a paved roadway may be estimated using the following empirical expression⁴:

$$e = k \left(\frac{sL}{0.5} \right)^p \quad (\text{g/VKT})$$

$$e = k \left(\frac{sL}{0.7} \right)^p \quad (\text{lb/VMT})$$

where: e = particulate emission factor, g/VKT (lb/VMT)
L = total road surface dust loading, g/m² (grains/ft²)
s = surface silt content, fraction of particles
 < 75 μm diameter (American Association of
 State Highway Officials)
k = base emission factor, g/VKT (lb/VMT)
p = exponent (dimensionless)



11.2.5-1, Deposition and removal processes.

The total loading (excluding litter) is measured by sweeping and vacuuming lateral strips of known area from each active travel lane. The silt fraction is determined by measuring the proportion of loose dry road dust that passes a 200 mesh screen, using the ASTM-C-136 method. Silt loading is the product of total loading and silt content.

The base emission factor coefficients, k , and exponents, p , in the equation for each size fraction are listed in Table 11.2.5-1. Total suspended particulate (TSP) denotes that particle size fraction of airborne particulate matter that would be collected by a standard high volume sampler.

TABLE 11.2.5-1. PAVED URBAN ROAD EMISSION FACTOR EQUATION PARAMETERS^a

Particle Size Fraction ^b	k g/VKT (lb/VMT)	p
TSP	5.87 (0.0208)	0.9
$\leq 15 \mu\text{m}$	2.54 (0.0090)	0.8
$\leq 10 \mu\text{m}$	2.28 (0.0081)	0.8
$\leq 2.5 \mu\text{m}$	1.02 (0.0036)	0.6

^aReference 4. See page 11.2.5-1 for equation. TSP = total suspended particulate.

^bAerodynamic diameter.

Microscopic analysis indicates the origin of material collected on high volume filters to be about 40 weight percent combustion products and 59 percent mineral matter, with traces of biological matter and rubber tire particles. The small particulate is mainly combustion products, while most of the large material is of mineral origin.

11.2.5.3 Emissions Inventory Applications⁴

For most emissions inventory applications involving urban paved roads, actual measurements of silt loading will probably not be made. Therefore, to facilitate the use of the previously described equation, it is necessary to characterize silt loadings according to parameters readily available to persons developing the inventories. It is convenient to characterize variations in silt loading with a roadway classification system, and this is presented in Table 11.2.5-2. This system generally corresponds to the classification systems used by transportation agencies, and thus the data necessary for an emissions inventory - number of road kilometers per road category and traffic counts - should be easy to obtain. In some situations, it may be necessary to combine this silt loading information with sound engineering judgment in order to approximate the loadings for roadway types not specifically included in Table 11.2.5-2.

TABLE 11.2.5-2. PAVED URBAN ROADWAY CLASSIFICATION^a

Roadway Category	Average Daily Traffic (Vehicles)	Lanes
Freeways/expressways	> 50,000	≥ 4
Major streets/highways	> 10,000	≥ 4
Collector streets	500 - 10,000	2 ^b
Local streets	< 500	2 ^c

^aReference 4.

^bRoad width ≥ 32 ft.

^cRoad width < 32 ft.

A data base of 44 samples analyzed according to consistent procedures may be used to characterize the silt loadings for each roadway category.⁴ These samples, obtained during recent field sampling programs, represent a broad range of urban land use and roadway conditions. Geometric means for this data set are given by sampling location and roadway category in Table 11.2.5-3.

TABLE 11.2.5-3. SUMMARY OF SILT LOADINGS (sL) FOR PAVED URBAN ROADWAYS^a

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

^aReference 4. \bar{X}_g = geometric mean based on corresponding n sample size. Dash = not available. To convert g/m² to grains/ft² multiply g/m² by 1.4337.

These sampling locations can be considered representative of most large urban areas in the United States, with the possible exception of those in the Southwest. Except for the collector roadway category, the mean silt loadings do not vary greatly from city to city, though the St. Louis mean for major roads is somewhat lower than those of the other four cities. The substantial variation within the collector roadway category is probably attributable to the effects of land use around the specific sampling locations. It should also be noted that an examination of data collected at three cities in Montana during early spring indicates that winter road sanding may produce loadings five to six times higher than the means of the loadings given in Table 11.2.5-3 for the respective road categories.⁵

Table 11.2.5-4 presents the emission factors by roadway category and particle size. These were obtained by inserting the above mean silt loadings into the equation on page 11.2.5-1. These emission factors can be used directly for many emission inventory purposes. It is important to note that the paved road emission factors for TSP agree quite well with those developed from previous testing of roadway sites in the major street and highway category, yielding mean TSP emission factors of 4.3 grams/VKT (Reference 6) and 2.6 grams/VKT (Reference 7).

TABLE 11.2.5-4. RECOMMENDED PARTICULATE EMISSION FACTORS FOR SPECIFIC ROADWAY CATEGORIES AND PARTICLE SIZE FRACTIONS

Roadway Category	Emission Factor			
	TSP g/VKT (1b/VMT)	$\leq 15 \mu\text{m}$ g/VKT (1b/VMT)	$\leq 10 \mu\text{m}$ g/VKT (1b/VMT)	$\leq 2.5 \mu\text{m}$ g/VKT (1b/VMT)
Local streets	15 (0.053)	5.8 (0.021)	5.2 (0.018)	1.9 (0.0067)
Collector streets	10 (0.035)	4.1 (0.015)	3.7 (0.013)	1.5 (0.0053)
Major streets/ highways	4.4 (0.016)	2.0 (0.0071)	1.8 (0.0064)	0.84 (0.0030)
Freeways/ expressways	0.35 (0.0012)	0.21 (0.00074)	0.19 (0.00067)	0.16 (0.00057)

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11.2.6 INDUSTRIAL PAVED ROADS

11.2.6.1 General

Various field studies have indicated that dust emissions from industrial paved roads are a major component of atmospheric particulate matter in the vicinity of industrial operations. Industrial traffic dust has been found to consist primarily of mineral matter, mostly tracked or deposited onto the roadway by vehicle traffic itself when vehicles enter from an unpaved area or travel on the shoulder of the road, or when material is spilled onto the paved surface from haul truck traffic.

11.2.6.2 Emissions And Correction Parameters

The quantity of dust emissions from a given segment of paved road varies linearly with the volume of traffic. In addition, field investigations have shown that emissions depend on correction parameters (road surface silt content, surface dust loading and average vehicle weight) of a particular road and associated vehicle traffic.¹⁻²

Dust emissions from industrial paved roads have been found to vary in direct proportion to the fraction of silt (particles <75 μm in diameter) in the road surface material.¹⁻² The silt fraction is determined by measuring the proportion of loose dry surface dust that passes a 200 mesh screen, using the ASTM-C-136 method. In addition, it has also been found that emissions vary in direct proportion to the surface dust loading.¹⁻² The road surface dust loading is that loose material which can be collected by broom sweeping and vacuuming of the traveled portion of the paved road. Table 11.2.6-1 summarizes measured silt and loading values for industrial paved roads.

11.2.6.3 Predictive Emission Factor Equations

The quantity of total suspended particulate emissions generated by vehicle traffic on dry industrial paved roads, per vehicle kilometer traveled (VKT) or vehicle mile traveled (VMT) may be estimated, with a rating of B or D (see below), using the following empirical expression²:

$$E = 0.022 I \left(\frac{4}{n}\right) \left(\frac{s}{10}\right) \left(\frac{L}{280}\right) \left(\frac{W}{2.7}\right)^{0.7} \quad (\text{kg/VKT}) \quad (1)$$

$$E = 0.077 I \left(\frac{4}{n}\right) \left(\frac{s}{10}\right) \left(\frac{L}{1,000}\right) \left(\frac{W}{3}\right)^{0.7} \quad (\text{lb/VMT})$$

where: E = emission factor
I = industrial augmentation factor (dimensionless) (see below)
n = number of traffic lanes
s = surface material silt content (%)
L = surface dust loading, kg/km (lb/mile) (see below)
W = average vehicle weight, Mg (ton)

TABLE 11.2.6-1. TYPICAL SILT CONTENT AND LOADING VALUES FOR PAVED ROADS AT INDUSTRIAL FACILITIES^a

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

^aReferences 1-5. Brackets indicate values based on samples obtained at only one plant site.
^bMultiply entries by 1,000 to obtain stated units.

The industrial road augmentation factor (I) in the Equation 1 takes into account higher emissions from industrial roads than from urban roads. I = 7.0 for an industrial roadway which traffic enters from unpaved areas. I = 3.5 for an industrial roadway with unpaved shoulders where 20 percent of the vehicles are forced to travel temporarily with one set of wheels on the shoulder. I = 1.0 for cases in which traffic does not travel on unpaved areas. A value between 1.0 and 7.0 which best represents conditions for paved roads at a certain industrial facility should be used for I in the equation.

The equation retains the quality rating of B if applied to vehicles traveling entirely on paved surfaces (I = 1.0) and if applied within the range of source conditions that were tested in developing the equation as follows:

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

If I is >1.0, the rating of the equation drops to D because of the subjectivity in the guidelines for estimating I.

The quantity of fine particle emissions generated by traffic consisting predominately of medium and heavy duty vehicles on dry industrial paved roads, per vehicle unit of travel, may be estimated, with a rating of A, using the

$$E = k \left(\frac{sL}{12} \right)^{0.3} \quad (\text{kg/VKT}) \quad (2)$$

$$E = k(3.5) \left(\frac{sL}{0.35} \right)^{0.3} \quad (\text{lb/VMT})$$

where: E = emission factor
 sL = road surface silt loading, g/m² (oz/yd²)

The particle size multiplier (k) above varies with aerodynamic size range as follows:

Aerodynamic Particle Size
 Multiplier (k) For Equation 2
 (Dimensionless)

<u><15 μm</u>	<u><10 μm</u>	<u><2.5 μm</u>
0.28	0.22	0.081

To determine particulate emissions for a specific particle size range, use the appropriate value of k above.

The equation retains the quality rating of A, if applied within the range of source conditions that were tested in developing the equation as follows:

silt loading, 2 - 240 g/m² (0.06 - 7.1 oz/yd²)

mean vehicle weight, 6 - 42 Mg (7 - 46 tons)

The following single valued emission factors⁶ may be used in lieu of Equation 2 to estimate fine particle emissions generated by light duty vehicles on dry, heavily loaded industrial roads, with a rating of C:

Emission Factors For Light Duty
 Vehicles On Heavily Loaded Roads

<u><15 μm</u>	<u><10 μm</u>
0.12 kg/VKT (0.41 lb/VMT)	0.093 kg/VKT (0.33 lb/VMT)

These emission factors retain the assigned quality rating, if applied within the range of source conditions that were tested in developing the factors, as follows:

silt loading, 15 - 400 g/m² (0.44 - 12 oz/yd²)

mean vehicle weight, <4 Mg (<4 tons)

Also, to retain the quality ratings of Equations 1 and 2 when applied to a specific industrial paved road, it is necessary that reliable correction parameter values for the specific road in question be determined. The field and

laboratory procedures for determining surface material silt content and surface dust loading are given in Reference 2. In the event that site specific values for correction parameters cannot be obtained, the appropriate mean values from Table 11.2.6-1 may be used, but the quality ratings of the equations should be reduced by one level.

11.2.6.4 Control Methods

Common control techniques for industrial paved roads are broom sweeping, vacuum sweeping and water flushing, used alone or in combination. All of these techniques work by reducing the silt loading on the traveled portions of the road. As indicated by a comparison of Equations 1 and 2, fine particle emissions are less sensitive than total suspended particulate emissions to the value of silt loading. Consistent with this, control techniques are generally less effective for the finer particle sizes.⁴ The exception is water flushing, which appears preferentially to remove (or agglomerate) fine particles from the paved road surface. Broom sweeping is generally regarded as the least effective of the common control techniques, because the mechanical sweeping process is inefficient in removing silt from the road surface.

To achieve control efficiencies on the order of 50 percent on a paved road with moderate traffic (500 vehicles per day) requires cleaning of the surface at least twice per week.⁴ This is because of the characteristically rapid buildup of road surface material from spillage and the tracking and deposition of material from adjacent unpaved surfaces, including the shoulders (berms) of the paved road. Because industrial paved roads usually do not have curbs, it is important that the width of the paved road surface be sufficient for vehicles to pass without excursion onto unpaved shoulders. Equation 1 indicates that elimination of vehicle travel on unpaved or untreated shoulders would effect a major reduction in particulate emissions. An even greater effect, by a factor of 7, would result from preventing travel from unpaved roads or parking lots onto the paved road of interest.

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