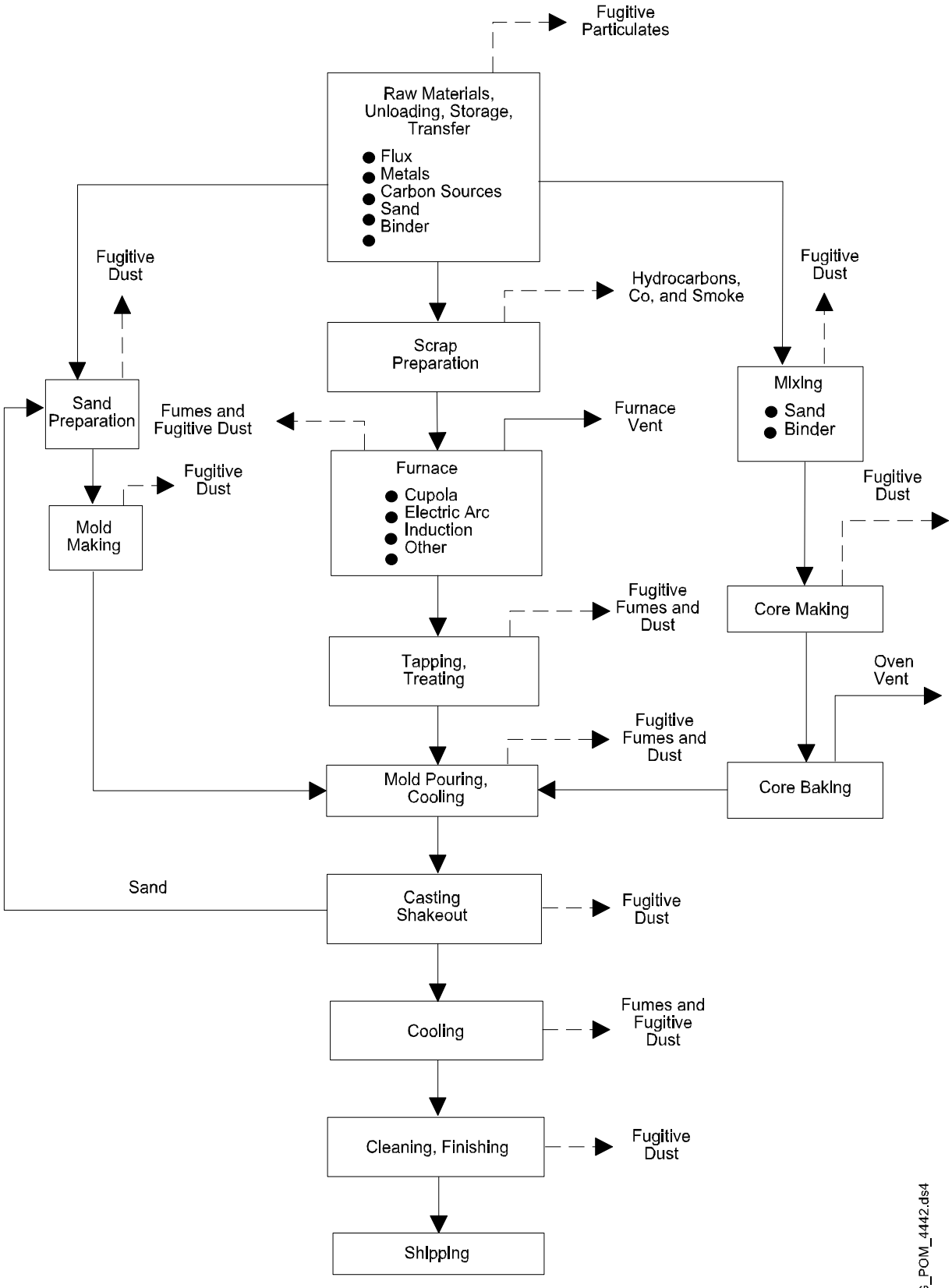

Figure 7-24. Emission Points in a Typical Iron and Steel Foundry

Source: Reference 244.

(shotblasting) cleaning, grinding, and heat treating are performed as necessary. The castings are then inspected and shipped to another industry for machining and/or assembly into a final product.[242]

In a typical foundry operation, charges to the melting unit are sorted by size and density and cleaned (as required) prior to being put in the melter. Charges consist of scrap metal, ingot, carbon (coke), and flux. Prepared charge materials are placed in crane buckets, weighed, and transferred into the melting furnace or cupola. The charge in a furnace or cupola is heated until it reaches a certain temperature and the desired chemistry of the melt has been attained. After the desired product is obtained, the molten metal is either poured out of the furnace into various sized teeming ladles and then into the molds or it is transferred to holding furnaces for later use.

7.7.2 Benzene Emissions From Iron and Steel Foundries

Organic compounds are emitted from various process steps in an iron and steel foundry, including scrap preparation, the furnace, tapping and treating, mold pouring and cooling, casting shakeout, sand cooling, and mold and core production. Benzene may be included among other organic compounds emitted from these process steps. Sources of organic emissions during these process steps include solvent degreasers used during scrap iron charge, coke, and organic binders and organic polymer networks that hold molds and cores together to form the castings.

Data from one testing program at a single gray iron foundry were averaged to develop a benzene emission factor (Table 7-12). The emission sources tested were sand cooler and belts, casting shakeouts and mixers, and pouring and cooling. Vapors from the sand cooler and belts and casting shakeouts and mixers were collected in hoods and ducted to a baghouse. Sampling for benzene was performed in accordance with EPA Method 18. All sampling was performed at the stack, after the control devices. Benzene emissions from the three emission sources were detected; however, because of limited process data availability, a

TABLE 7-12. BENZENE EMISSION FACTOR FOR IRON FOUNDRIES

SCC	Emission Source	Control Device(s)	Emission Factor lb/ton (kg/Mg)	Emission Factor Rating
3-04-003-98	Sand cooling and belts	Baghouse	6.99×10^{-4} (3.50×10^{-4})[a]	D

Source: References 245 and 246.

[a] Factor is in lb (kg) of benzene emitted per ton (Mg) of sand cooled.

benzene emission factor could only be calculated for the sand cooler and belts, as reflected in Table 7-12.[245-246]

Benzene from sand coolers and belts and casting shakeouts and mixers may be emitted as a result of the heating during mold pouring of the organic binders used to form the casting. During mold pouring, the binder materials in the mold are exposed to temperatures near 2,550°F (1,400°C). At these temperatures, pyrolysis of the chemical binder may release organic chemicals, which become trapped in the sand inside the casting. During shakeout and sand cooling, the sand is exposed to the atmosphere and these organic chemicals may be released.

7.7.3 Control Technologies for Iron and Steel Foundries[244]

Scrap preparation with heat or solvent degreasers will emit organic compounds. Catalytic incinerators and afterburners can control about 95 percent of organic emissions.

Emissions released from melting furnaces include organic compounds. The highest concentrations of furnace emissions occur when furnace doors are open during charging, backcharging, alloying, slag removal, and tapping operations. These emissions can escape into the furnace building or can be collected and vented through roof openings. Emission controls for melting and refining operations involve venting furnace gases and fumes directly to a control device. Canopy hoods or special hoods near furnace doors and tapping points capture emissions and route them to emission control systems.

A cupola furnace typically has an afterburner, which achieves up to 95 percent efficiency. The afterburner is located in the furnace stack to oxidize CO and burn organic fumes, tars, and oils. Reducing these contaminants protects the particulate control device from possible plugging and explosion. Toxic emissions from cupolas include both organic and inorganic materials. Cupolas produce the most toxic emissions compared to other melting equipment. During melting in an electric arc furnace, hydrocarbons are emitted from

vaporization and incomplete combustion of any oil remaining on the scrap iron charge. Electric induction furnaces emit negligible amounts of hydrocarbon emissions, and are typically uncontrolled except during charging and pouring operations.

Organic emissions are generated during the refining of molten iron before pouring and from the mold and core materials during pouring. Toxic emissions of halogenated and aromatic hydrocarbons are released in the refining process. Emissions from pouring normally are captured by a collection system and vented, either controlled or uncontrolled, to the atmosphere. Emissions continue as the molds cool.

Organics are emitted in mold and core production operations from core baking and mold drying. Afterburners and catalytic incinerators can be used to control organics emissions.

In addition to organic binders, molds and cores may be held together in the desired shape by means of a cross-linked organic polymer network. This network of polymers undergoes thermal decomposition when exposed to the very high temperatures of casting, typically 2,550°F (1,400°C). At these temperatures it is likely that pyrolysis of the chemical binder will produce a complex of free radicals that will recombine to form a wide range of chemical compounds having widely differing concentrations.

There are many different types of resins currently in use, with diverse and toxic compositions. No data are available for determining the toxic compounds in a particular resin that are emitted to the atmosphere and to what extent these emissions occur.

7.8 PORTLAND CEMENT PRODUCTION

Most of the hydraulic cement produced in the United States is Portland cement--a cementitious, crystalline compound composed of metallic oxides. The end-product cement, in its fused state, is referred to as “clinker.” Raw materials used in the process can be

calcium carbonate- and aluminum-containing limestone, iron, silicon oxides, shale, clay, and sand.[247] As of December 1990, there were 112 Portland cement plants in the United States operating 213 kilns with a total annual clinker capacity of 80 million tons (73.7 million Mg). The kiln population included 80 wet process kilns and 133 dry process kilns.[247] U.S. Portland cement plants are listed in Table 7-13 .

7.8.1 Process Description for the Portland Cement Industry

In Portland cement production, most raw materials typically are quarried on site and transferred by conveyor to crushers and raw mills. After the raw materials are reduced to the desired particle size, they are blended and fed to a large rotary kiln. The feed enters the kiln at the elevated end, and the burner is located at the opposite end. The raw materials are then changed into cementitious oxides of metal by a countercurrent heat exchange process. The materials are continuously and slowly moved to the low end by the rotation of the kiln while being heated to high temperatures (2,700°F [1,482°C]) by direct firing (Stream 3 in Figure 7-25). In this stage, chemical reactions occur, and a rock-like substance called "clinker" is formed. This clinker is then cooled, crushed, and blended with gypsum to produce Portland cement.[247] The cement is then either bagged or bulk-loaded and transported out.[248]

Cement may be made via a wet or a dry process. Many older kilns use the wet process. In the past, wet grinding and mixing technologies provided more uniform and consistent material mixing, resulting in a higher quality clinker. Dry process technologies have improved, however, to the point that all of the new kilns since 1975 use the dry process.[249] In the wet process, water is added to the mill while the raw materials are being ground. The resulting slurry is fed to the kiln. In the dry process, raw materials are also ground finely in a mill, but no water is added and the feed enters the kiln in a dry state.

More fuel is required for the wet process than the dry process to evaporate the water from the feed. However, for either the wet or dry process, Portland cement production is fuel-intensive. The fuel burned in the kiln may be natural gas, oil, or coal. Many cement

TABLE 7-13. SUMMARY OF PORTLAND CEMENT PLANT CAPACITY INFORMATION

Location	Number of Plants (kilns)	Capacity 10^3 tons/yr (10^3 Mg/yr)
Alabama	5 (6)	4,260 (3,873)
Alaska	1 (0)[a]	0 (0)
Arizona	2 (7)	1,770 (1,609)
Arkansas	2 (5)	1,314 (1,195)
California	12 (20)	10,392 (9,447)
Colorado	3 (5)	1,804 (1,640)
Florida	6 (8)	3,363 (3,057)
Georgia	2 (4)	1,378 (1,253)
Hawaii	1 (1)	263 (239)
Idaho	1 (2)	210 (191)
Illinois	4 (8)	2,585 (2,350)
Indiana	4 (8)	2,830 (2,573)
Iowa	4 (7)	2,806 (2,551)
Kansas	4 (11)	1,888 (1,716)
Kentucky	1 (1)	724 (658)
Maine	1 (1)	455 (414)
Maryland	3 (7)	1,860 (1,691)
Michigan	5 (9)	4,898 (4,453)
Mississippi	1 (1)	504 (458)
Missouri	5 (7)	4,677 (4,252)
Montana	2 (2)	592 (538)
Nebraska	1 (2)	961 (874)
Nevada	1 (2)	415 (377)
New Mexico	1 (2)	494 (449)
New York	4 (5)	3,097 (2,815)
Ohio	4 (5)	1,703 (1,548)

(continued)

TABLE 7-13. CONTINUED

Location	Number of Plants (kilns)	Capacity 10^3 tons/yr (10^3 Mg/yr)
Oklahoma	3 (7)	1,887 (1,715)
Oregon	1 (1)	480 (436)
Pennsylvania	11 (24)	6,643 (6,039)
South Carolina	3 (7)	2,579 (2,345)
South Dakota	1 (3)	766 (696)
Tennessee	2 (3)	1,050 (955)
Texas	12 (20)	8,587 (7,806)
Utah	2 (3)	928 (844)
Virginia	1 (5)	1,117 (1,015)
Washington	1 (1)	473 (430)
West Virginia	1 (3)	822 (747)
Wyoming	1 (1)	461 (419)

Source: Reference 247.

[a] Grinding plant only.

plants burn coal, but supplemental fuels such as waste solvents, chipped rubber, shredded municipal garbage, and coke have been used in recent years.[247] A major trend in the industry is the increased use of waste fuels. In 1989, 33 plants in the United States and Canada reported using waste fuels; the number increased to 55 plants in 1990.[247]

The increased use of hazardous waste-derived fuels (HWDFs) for the kilns is attributed to lower cost and increased availability. As waste generators reduce or eliminate solvents from their waste steams, the streams contain more sludge and solids. As a result, two new hazardous waste fueling methods have emerged at cement kilns. The first method pumps solids (either slurried with liquids or dried and ground) into the hot end of the kiln. The second method (patented by cement kiln processor and fuel blender Cadence, Inc.) introduces containers of solid waste into the calcining zone of the kiln.[250]

The kiln system for the manufacture of Portland cement by dry process with preheater is shown in Figure 7-25. The raw material enters a four-stage suspension preheater, where hot gases from the kiln heat the raw feed and provide about 40-percent calcination (Stream 1) before the feed enters the kiln. Some installations include a precalcining furnace (Stream 2), which provides about 85 percent calcination before the feed enters the kiln.[247]

7.8.2 Benzene Emissions from the Portland Cement Industry and Regulatory Analysis

The raw materials used by some facilities may contain organic compounds, which become a source of benzene emissions during the heating step. However, fuel combustion to heat the kiln is believed to be the greater source of benzene emissions. As shown in Table 7-14, benzene is emitted when either fossil fuels or HWDFs are combusted in the kiln.[247,249,251]

Facilities that burn HWDF are subject to the Boilers and Industrial Furnaces (BIF) rule promulgated February 21, 1991, under the Resource Conservation and Recovery Act (RCRA). The BIF rule requires that a facility that burns hazardous waste demonstrate a

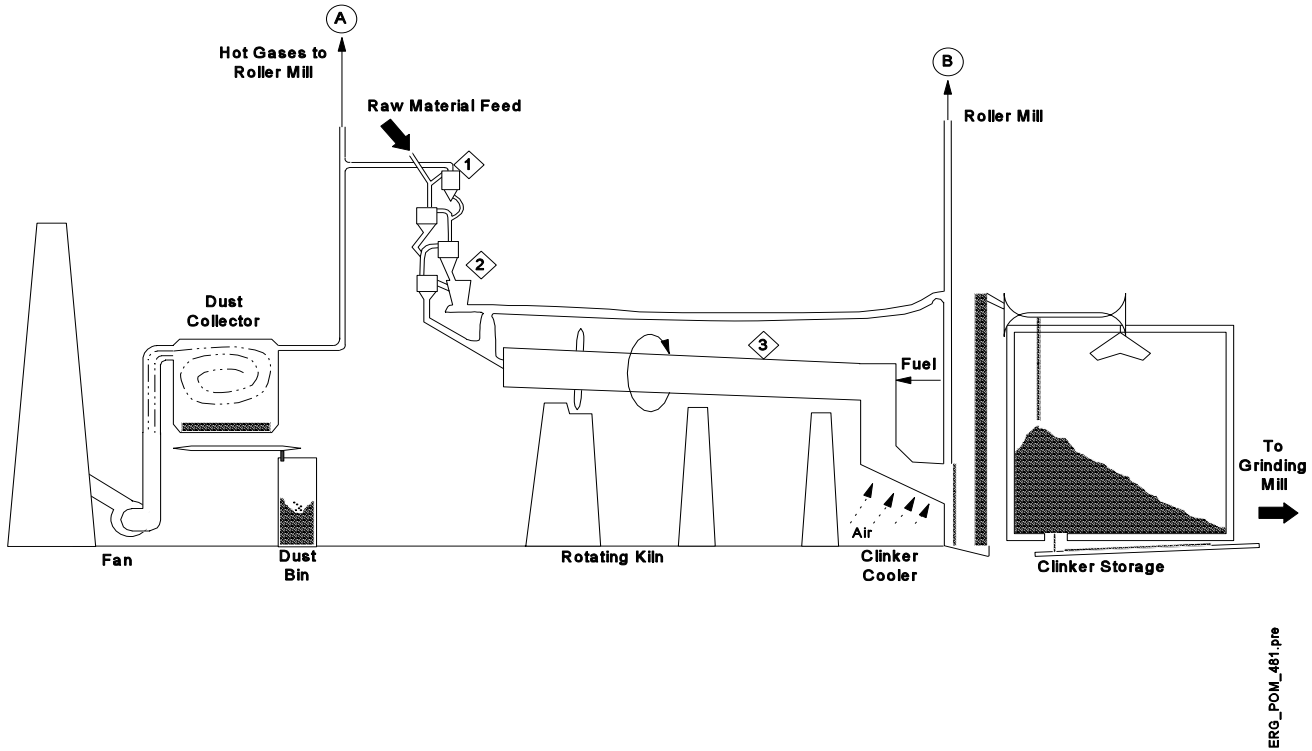

Figure 7-25. Process Diagram of Portland Cement Manufacture by Dry Process With Preheater

Source: Reference 247.

TABLE 7-14. SUMMARY OF EMISSION FACTORS FOR THE PORTLAND CEMENT INDUSTRY

SCC and Description	Emissions Source	Control Device	Emission Factor lb/ton (kg/Mg)[a]	Factor Rating	Reference
3-05-007-06 Cement Manufacturing - Wet Process - Kilns	Kiln--Burning Hazardous Waste Exclusively, or with Coal or Coke	EP	3.7×10^{-3} (1.8×10^{-3})	B	247, 251
	Kiln--Burning Hazardous Waste and Natural Gas as Fuel	EP	7.5×10^{-3} (3.7×10^{-3})	D	251
	Kiln--Burning Hazardous Waste and Coal at High Combustion Temperature	EP	3.9×10^{-6} (1.9×10^{-6})	D	251
3-05-006-06 Cement Manufacturing - Dry Process	Kiln--Burning Coal in Precalciner Process	FF	1.6×10^{-2} (8×10^{-3})	E	249
	Kiln--Burning Coal and 20 percent TDF[b]	FF	0.17 g/MMBtu	E	249

[a] Expressed as lb (kg) of benzene emitted per Mg (ton) of clinker produced.
[b] Facility burns 65 tons (59 Mg) TDF per day (6,000 tires); MMBtu/ton of clinker produced not reported for this facility.

EP = Electrostatic Precipitator.
FF = Fabric Filter.
TDF = Tire-derived fuel.

99.99 percent destruction efficiency for principal organic hazardous constituents in the waste stream. To guard against products of incomplete combustion, the BIF rule limits CO levels in the kiln and or total hydrocarbon levels in stack gases.[250,251] In addition, a NESHAP for control of HAPs from Portland Cement Kilns is under development.

Table 7-14 presents a summary of benzene emission factors for wet process cement kilns controlled with electrostatic precipitators burning HWDF in conjunction with other fuels.

7.9 HOT-MIX ASPHALT PRODUCTION

In 1994, there were approximately 3,600 asphalt hot-mix plants.[252] Approximately 40 percent of companies that operate hot-mix plants operate a single plant. Because plants must be located near the job site, plants are concentrated in areas where the highway and road network is concentrated.[253] Additional information on the locations of individual hot-mix asphalt facilities can be obtained by contacting the National Asphalt Pavement Association in College Park, Maryland.

7.9.1 Process Description

There are three types of hot-mix asphalt plants operating in the United States: batch-mix, continuous-mix, and drum-mix. At batch-mix and continuous-mix plants, the aggregate drying process is performed separately from the mixing of aggregate with asphalt cement. Drum-mix plants combine these two processes. Production capacities for all three types of plants range from 40 to 600 tons (36 to 544 Mg) of hot mix per hour. Almost all plants in use are of either the batch-mix or the drum-mix types. Less than half a percent of operating hot-mix asphalt plants are of the continuous-mix variety.[79] Over 80 percent of all hot-mix asphalt production plants are mobile.[245]

In the production of hot-mix asphalt (also referred to as asphalt concrete), aggregate is heated to eliminate moisture and then mixed with hot asphalt cement. The resulting hot mixture is pliable and able to be compacted and smoothed. When the hot-mix asphalt cools and hardens, it provides a waterproof and durable pavement for roads, driveways, parking lots, and runways.

Aggregate, the basic raw material of hot-mix asphalt, consists of any hard, inert mineral material, usually gravel, sand, and mineral filler. Aggregate typically comprises between 90 and 95 percent by weight of the asphalt mixture. Because aggregate provides most of the load-bearing properties of a pavement, the performance of the pavement depends on selection of the proper aggregate.

Asphalt cement is used as the binding agent for aggregate. It prevents moisture from penetrating the aggregate, and it acts as a cushioning agent. Typically, asphalt cement constitutes 4 to 6 percent by weight of a hot-mix asphalt mixture.[253]

As with the asphalt flux used to produce asphalt roofing products, asphalt cement is obtained from the distillation of crude oil. It is classified into grades under one of several classification schemes. The most commonly used scheme classifies asphalt cement based on its viscosity at 140°F (60°C). The more viscous the asphalt cement, the higher its numerical rating. An asphalt cement of grade AC-40 is considered a hard asphalt (i.e., a viscosity of 4,000 grams per centimeter per second [g/cm-s or poises]), whereas an asphalt cement of grade AC-2.5 is considered a soft asphalt (i.e., a viscosity of 250 g/cm-s [poises]).

Several western States use a second classification scheme that measures viscosity of the asphalt cement after a standard simulated aging period. This simulated aging period consists of exposure to a temperature of 325°F (163°C) for 5 hours. Viscosity is measured at 140°F (60°C), with grades ranging from AR-1000 for a soft asphalt cement (1000 g/cm-s [poises]) to AR-16000 for a hard asphalt cement (16,000 g/cm-s [poises]).

A third classification scheme is based on the penetration allowed by the asphalt cement. Grade designation 40 to 50 means that a needle with a weight attached will penetrate the asphalt cement between 40 and 50 tenths of a millimeter under standard test conditions. The hard asphalt cements have penetration ratings of 40 to 50, whereas the soft grades have penetration ratings of 200 to 300.[253]

The asphalt cement grade selected for different hot-mix asphalts depends on the type of pavement, climate, and type and amount of traffic expected. Generally, asphalt pavement bearing heavy traffic in warm climates would require a harder asphalt cement than pavement subject to either light traffic or cold climate conditions.

Another material that is used to a greater extent in the production of new or virgin hot-mix asphalt is recycled asphalt pavement (RAP), which is pavement material that has been removed from existing roadways. This RAP material is now used by virtually all companies in their hot-mix asphalt mixtures. The Surface Transportation Assistance Act of 1982 encourages recycling by providing a 5-percent increase in Federal funds to State agencies that recycle asphalt pavement. Rarely does the RAP comprise more than 60 percent by weight of the new asphalt mixture. Twenty-five percent RAP is typical in batch plants, whereas 40 to 50 percent RAP mixtures are typical in drum-mix plants.[253]

Rejuvenating agents are sometimes added to hot-mix asphalts where they are blended with RAP, which brings the weathered and aged asphalt cement in the recycled mixture up to the specifications of a new asphalt mixture. Usually, a soft asphalt cement, a specially prepared high-viscosity oil, or a hard asphalt cement blended with a low-viscosity oil are used as rejuvenating agents. The amount of rejuvenating agent added depends on the properties of the RAP and on the specifications for the hot-mix asphalt product.

The primary processes of a typical batch-mix hot-mix asphalt facility are illustrated in Figure 7-26.[252] Aggregate of various sizes is stockpiled at the plant for easy access. The moisture content of the stockpiled aggregate usually ranges from 3 to 5 percent.

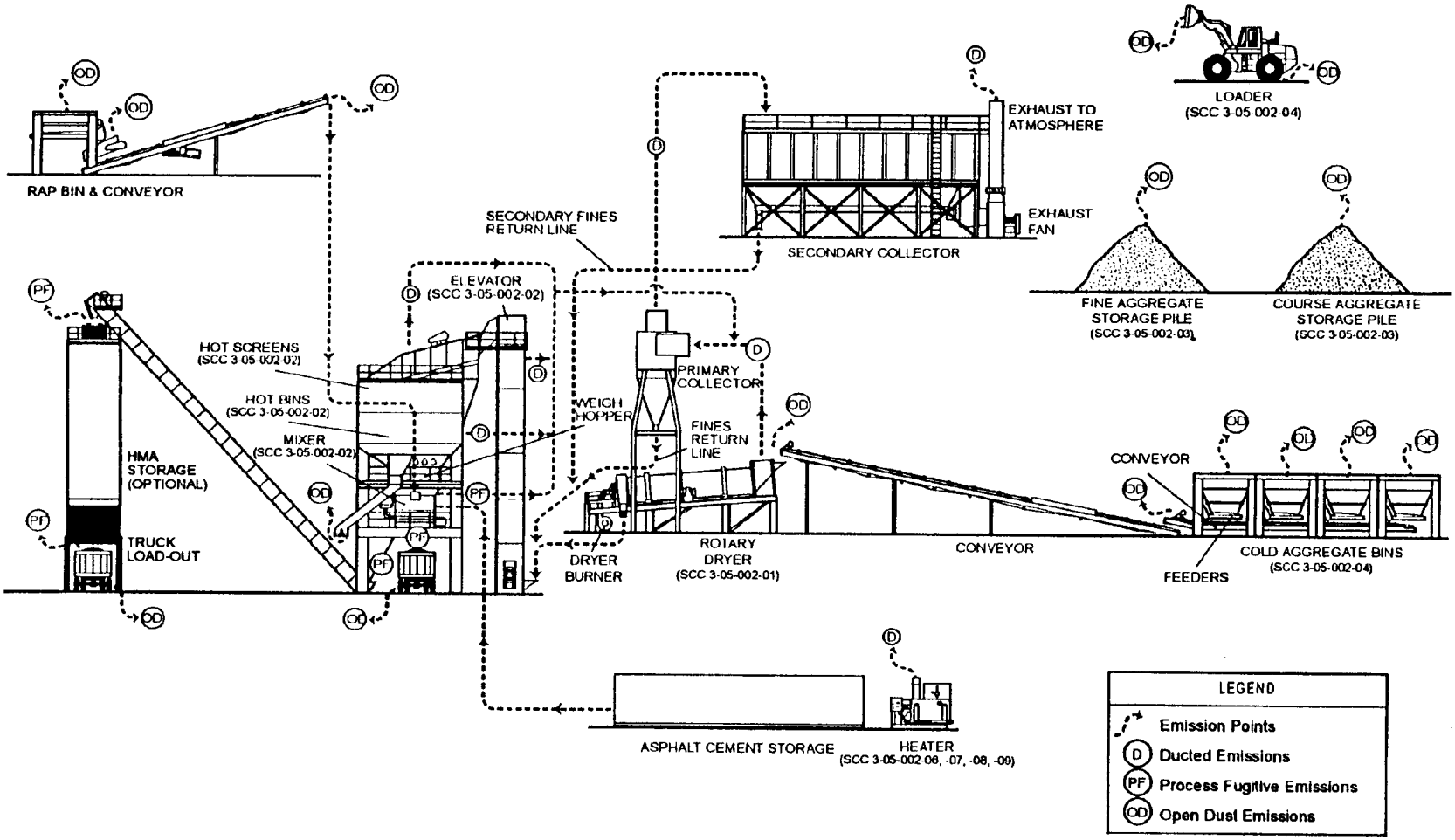

Figure 7-26. General Process Flow Diagram for Batch Mix Asphalt Paving Plants

Source: Reference 252.

The moisture content of recycled hot-mix asphalt typically ranges from 2 to 3 percent. The different sizes of aggregate are typically transported by front-end loader to separate cold feed bins and metered onto a feeder conveyor belt through gates at the bottom of the bins. The aggregate is screened before it is fed to the dryer to keep oversize material out of the mix.

The screened aggregate is then fed to a rotating dryer with a burner at its lower (discharge) end that is fired with fuel oil, natural gas, or propane. The dryer removes moisture from the aggregate and heats the aggregate to the proper mix temperature. Inside the dryer are longitudinal flights (metal slats) that lift and tumble the aggregate, causing a curtain of material to be exposed to the heated gas stream. This curtain of material provides greater heat transfer to the aggregate than would occur if the aggregate tumbled along the bottom of the drum towards the discharge end. Aggregate temperature at the discharge end of the dryer is about 300°F (149°C). The amount of aggregate that a dryer can heat depends on the size of the drum, the size of the burner, and the moisture content of the aggregate. As the amount of moisture to be removed from the aggregate increases, the effective production capacity of the dryer decreases.

Vibrating screens segregate the heated aggregate into bins according to size. A weigh hopper meters the desired amount of the various sizes of aggregate into a pugmill mixer. The pugmill typically mixes the aggregate for approximately 15 seconds before hot asphalt cement from a heated tank is sprayed into the pugmill. The pugmill thoroughly mixes the aggregate and hot asphalt cement for 25 to 60 seconds. The finished hot-mix asphalt is either directly loaded into trucks or held in insulated and/or heated storage silos. Depending on the production specifications, the temperature of the hot-mix asphalt product mix can range from 225 to 350°F (107 to 177°C) at the end of the production process.

When a hot mix containing RAP is produced, the aggregate is superheated (compared to totally virgin hot-mix asphalt production) to about 600°F (315°C) to ensure sufficient heat transfer to the RAP when it is mixed with the virgin materials. The RAP

material may be added either to the pugmill mixer or at the discharge end of the dryer. Rarely is more than 30 percent RAP used in batch plants for the production of hot-mix asphalt.

Continuous-mix plants are very similar in configuration to batch plants. Continuous-mix plants have smaller hot bins (for holding the heated aggregate) than do batch plants. Little surge capacity is required of these bins because the aggregate is continuously metered and transported to the mixer inlet by a conveyor belt. Asphalt cement is continuously added to the aggregate at the inlet of the mixer. The aggregate and asphalt cement are mixed by the action of rotating paddles as they are conveyed through the mixer. An adjustable dam at the outlet end of the mixer regulates the mixing time and also provides some surge capacity. The finished mix is transported by a conveyor belt to either a storage silo or surge bin.[253]

Drum-mix plants dry the aggregate and mix it with the asphalt cement in the same drum, eliminating the need for the extra conveyor belt, hot bins and screens, weigh hopper, and pugmill of batch-mix plants. The drum of a drum-mix plant is much like the dryer of a batch plant, but it typically has more flights than do batch dryers to increase veiling of the aggregate and to improve overall heat transfer. The burner in a drum-mix plant emits a much bushier flame than does the burner in a batch plant. The bushier flame is designed to provide earlier and greater exposure of the virgin aggregate to the heat of the flame. This design also protects the asphalt cement, which is injected away from the direct heat of the flame.[253]

Initially, drum-mix plants were designed to be parallel flow as depicted in Figure 7-27.[252] Recently, the counterflow drum-mix plant design shown in Figure 7-28 has become popular.[79] The parallel flow drum-mix process is a continuous mixing type process using proportioning cold-feed controls for the process materials. Aggregate, which has been proportioned by gradations, is introduced to the drum at the burner end. As the drum rotates, the aggregate as well as the combustion products move toward the other end of the drum in parallel. Liquid asphalt cement flow is controlled by a variable flow pump that is electronically linked to the virgin aggregate and RAP weigh scales. The asphalt cement is