

3.0 EMISSION CONTROL TECHNIQUES

This chapter discusses emission control techniques for reducing HAP emissions from recovery furnaces, BLO systems, SDT's, and lime kilns located at kraft pulp and paper mills. Recovery furnaces include DCE recovery furnaces and NDCE recovery furnaces. Add-on controls and equipment changes/modifications are discussed in Sections 3.1 and 3.2, respectively. Both PM and gaseous HAP control techniques are included in this discussion. Section 3.3 contains the references cited in this chapter.

Tables 3-1 and 3-2 present applicable control techniques for reducing PM and gaseous HAP emissions, respectively, from the aforementioned combustion sources located at kraft pulp and paper mills. These control techniques and their effectiveness in reducing PM and gaseous HAP emissions are discussed below.

3.1 ADD-ON CONTROLS

This section describes the various add-on air pollution control equipment that can be applied to the combustion sources located in the chemical recovery areas at kraft pulp and paper mills. Sections 3.1.1, 3.1.2, and 3.1.3 describe ESP's, wet scrubbers, and BLO control, respectively; each section presents a description of the control equipment and describes the performance of the equipment in controlling HAP (PM and/or gaseous) emissions from the applicable combustion sources.

3.1.1 Electrostatic Precipitators

Electrostatic precipitators are a demonstrated control technique for reducing PM emissions from kraft recovery furnaces and lime kilns. The PM emissions from over 98 percent of kraft recovery furnaces and approximately 10 percent of kraft lime kilns are controlled with ESP's.¹ A general description of the

TABLE 3-1. PARTICULATE MATTER HAP CONTROL TECHNIQUES

Source	Control technique	Percent PM reduction
Recovery furnace	ESP	99+
Lime kiln	ESP	99+
	Venturi scrubber	99+
SDT	Wet scrubber	99+

TABLE 3-2. GASEOUS HAP CONTROL TECHNIQUES

Source	Control technique	Percent reduction	
		HCl	Other HAP's
NDCE recovery furnace systems	Packed-bed scrubber	Up to 99% or 5 ppmv ^a	-- ^b
	Elimination of black liquor from ESP system	--	72%
DCE recovery furnace system (includes air-sparging BLO system)	Packed-bed scrubber	Up to 99% or 5 ppmv ^a	-- ^b
	Conversion to NDCE recovery furnace with dry- ESP system ^c	-- ^d	93%
	Incineration of BLO vent gases	-- ^e	38% ^f
Lime kiln	Control makeup water quality in causticizing area	-- ^g	
SDT	Control makeup water quality in causticizing area	-- ^g	

^aControl efficiency depends on inlet HCl concentration. Based on manufacturers' guarantees, scrubbers can achieve either a 99 percent control efficiency or an outlet concentration of 5 ppmv.

^bInsufficient data are available to determine the emission reductions of other HAP's.

^cConversion includes replacement of the DCE recovery furnace with an NDCE recovery furnace and elimination of the BLO unit.

^dHCl emissions are highly variable. Available data indicate no overall change in HCl emissions is expected from converting a DCE recovery furnace system to an NDCE recovery furnace.

^eHCl is not emitted from BLO systems.

^fThe overall percent reduction is based on average HAP emission factors for DCE recovery furnaces and air-sparging BLO systems, and on a control efficiency of 98 percent for HAP's emitted from the BLO system.

^gWastewater control option performance is addressed in a separate wastewater regulatory development program.

types of ESP's used to control PM emissions from kraft recovery furnaces and lime kilns is provided in Section 3.1.1.1, below. The performance of these ESP's is discussed in Section 3.1.1.2.

3.1.1.1 Description. The ESP's used to control PM emissions from kraft recovery furnaces and lime kilns are generally classified as plate-wire ESP's. In plate-wire ESP's, the flue gas flows between parallel sheet metal plates and high-voltage electrodes. The flue gas passes between collecting plates into a field of ions that have been negatively charged by the high-voltage electrodes located between the plates.² Each paired set of electrodes and plates forms a separate electrostatic field within the ESP. Electrostatic precipitators used to control PM emissions from kraft recovery furnaces typically have two parallel precipitator chambers (i.e., flue gas passages) with three or four electrostatic fields per chamber. Lime kiln ESP's typically have one chamber with two or three electrostatic fields.¹

As the flue gas passes through each electrostatic field, the particles suspended in the flue gas are bombarded by the ions, imparting a negative charge to the particles. The negatively charged particles then migrate towards the positively charged or grounded "collecting" plates, where the particles transfer a portion of their charge, depending upon their resistivity. The particles are kept on the collecting plates by the electrostatic field and the remaining charge.³ At periodic intervals, the collection plates are knocked ("rapped"), and the accumulated PM falls into the bottom of the ESP. The recovered PM is subsequently recycled to the black liquor in recovery furnace applications or, in lime kiln applications, fed back to the kiln. The ESP's used on recovery furnaces may be designed with either a wet or dry bottom. In wet-bottom ESP's, the collected PM falls directly into a pool of liquid, which may be black liquor or water, in the bottom of the ESP. In dry-bottom ESP's, the collected PM falls to the (dry) bottom of the ESP and is transferred from the ESP bottom to a mix tank (containing black liquor) via drag-chain or screw conveyors. Black liquor is

sometimes used to transport the dry collected PM to the mix tank. More recent ESP installations employ a dry PM return system to transport the PM to the mix tank. Because the PM removed by the ESP is recycled to the black liquor in the mix tank, the ESP is an integral part of the chemical recovery loop as well as an air pollution control device.

The design of the plate-wire ESP's used to control PM emissions from recovery furnaces and lime kilns may include either weighted-wire electrodes or rigid electrodes. With the weighted-wire design, the wire electrodes are suspended inside the ESP, and weights are attached to the wires to maintain tension. In the rigid-electrode design, the discharge electrodes are rigid tubes with pointed corona emitters welded to the surface; each tube replaces two weighted wires. Although the weighted-wire design has been available for more than 50 years, rigid-electrode ESP's have only been available since the late 1970's. The rigid-electrode ESP represents the current stage of development in ESP technology and offers the following advantages over the weighted-wire design: a higher tolerance of in-service abuse (no wires to break), better collection efficiencies, and better cleaning characteristics.⁴ According to one manufacturer, all new ESP installations in the pulp and paper industry since 1990 have rigid-electrode designs.⁵ Additionally, since 1981, 64 of the 66 (97 percent) recovery furnace ESP installations supplied by this manufacturer have been of the rigid-electrode design, and approximately 80 percent of the lime kiln ESP applications use rigid-electrode designs.⁵ Figure 3-1 is a schematic of a rigid-electrode, plate-wire ESP.

The average lifetime of an ESP in service on a kraft recovery furnace varies depending upon the type of ESP bottom (i.e., wet vs. dry), the inlet temperature of the gases, and maintenance practices. The lifetime of ESP's used to control PM emissions from recovery furnaces with NDCE's, which tend to operate with dry-bottom ESP's, typically ranges from 12 to 15 years.⁴ After that point, major repairs or a rebuild may be required. Recovery furnaces with DCE's tend to have cooler inlet

Figure 3-1. Rigid-electrode ESP.

gases and wet-bottom ESP's; these two factors promote corrosion through condensation of acid gases and shorten the life of the ESP. The lifetime of an ESP on a DCE recovery furnace typically ranges from 7 to 10 years.⁴

Lime kiln ESP's operate in a "milder" environment (i.e., hotter temperatures prevent any acid gases from condensing and corroding the ESP, and the primary constituent of the PM collected is lime, which creates an alkaline environment that further protects the ESP from acid gas corrosion). Therefore, lime kiln ESP's have fewer corrosion problems than do recovery furnace ESP's. The expected lifetime of a lime kiln ESP is typically more than 15 years.⁶

The size of the ESP is often expressed in terms of the specific collecting area (SCA), which is defined as the total collecting plate surface area divided by the flue gas flow rate. Specific collecting areas of ESP's used to control PM emissions from kraft recovery furnaces and lime kilns typically range from about 39 to 160 square meters per cubic meter per second ($m^2/[m^3/sec]$) (200 to 800 square feet per 1,000 actual cubic feet per minute [$ft^2/1,000\ acfm$]).¹ The SCA's of ESP's used to control emissions from DCE recovery furnaces tend to be somewhat lower than those associated with NDCE recovery furnaces. The average SCA for ESP's used to control emissions from DCE recovery furnaces is approximately 15 percent lower than for NDCE recovery furnaces.¹ The primary reason for the difference is that the DCE removes 20 to 40 percent of the PM before the ESP; therefore, the inlet loading of PM to the ESP operating on a DCE recovery furnace is lower than that of an NDCE recovery furnace.⁷ The lower SCA's for DCE recovery furnaces may also be because DCE recovery furnaces tend to be older than NDCE recovery furnaces, and most are not subject to the NSPS for Kraft Pulp Mills.

3.1.1.2 Performance. Electrostatic precipitators can control PM HAP emissions but provide no control of gaseous HAP emissions. Properly designed and operated ESP's used on kraft recovery furnaces and lime kilns routinely achieve PM removal efficiencies of 99 percent or greater. Although emission test

data from recovery furnace ESP's on PM HAP performance are limited, data collected from other combustion sources on the relative performance of ESP's for PM and metals indicate that those systems that achieve the greatest PM removal also provide the best performance for the HAP portion of the PM.⁸ Therefore, total PM performance can be used as a surrogate for PM HAP's.

Because performance guarantees made by ESP manufacturers and permit limits are usually in the form of outlet PM emission concentrations rather than in the form of achievable control efficiencies, outlet concentrations will be the focus of the discussion of the performance of ESP's on kraft recovery furnaces and lime kilns in the following sections. Following the format of the NSPS, all PM concentrations for recovery furnace emissions are corrected to 8 percent O₂, and those for lime kiln emissions are corrected to 10 percent O₂. The discussion below also addresses the factors that affect ESP performance.

3.1.1.2.1 Recovery furnaces. The PM emitted from the recovery furnace and subsequently recovered by the ESP is primarily composed of sodium sulfate (i.e., "saltcake") and sodium carbonate, neither of which are HAP's. Particulate matter HAP's, which are primarily metals (although small quantities of high-boiling-point semivolatile organic compounds also may be emitted in particle form), are emitted from the ESP in small quantities. For any single metal, the quantity emitted from either NDCE or DCE recovery furnaces is typically less than 140 kg/yr (300 lb/yr).⁹ The paragraphs below first discuss the outlet concentrations achievable by ESP's based on information compiled as a part of the previous NSPS development effort and on long-term performance data compiled by the State of Washington. Then factors that can affect ESP performance are described.

The NSPS for kraft recovery furnaces requires that PM emissions from recovery furnaces constructed, reconstructed, or modified after September 24, 1976 be less than or equal to 0.10 grams per dry standard cubic meter (g/dscm) (0.044 grains per dry standard cubic foot [gr/dscf] of flue gas).^{10,11} Based on installation dates, approximately 39 percent of NDCE recovery

furnaces (i.e., 50 NDCE recovery furnaces) and 4 percent of DCE recovery furnaces (i.e., 3 DCE recovery furnaces) are subject to the NSPS.¹² In addition, some NDCE and DCE recovery furnaces not subject to the NSPS are subject to State PM permit limits that are less than or equal to the NSPS limit.¹³ Therefore, about 25 percent of the 211 existing recovery furnaces nationwide are required by regulation to emit PM in concentrations less than or equal to 0.10 g/dscm (0.044 gr/dscf).

The NSPS emission limit was established based on the performance of a weighted-wire ESP design, taking into consideration maintenance issues such as wire breakage, the corrosive and sticky nature of the PM removed, any long-term deterioration in ESP performance, and the inherent variability of ESP performance.¹⁴ In considering these issues, EPA found that ESP's that formed the basis for the standard were installed with added insulation or heated shells to maintain the gas temperature throughout the precipitator to prevent corrosion.¹⁴ Also, although some amount of wire breakage was noted, most occurred soon after start-up and lessened in frequency with more operating time. A loss of 5 to 10 percent of the wires was determined to have no noticeable effect on the performance of the ESP.¹⁴ Finally, about long-term deterioration in ESP performance, manufacturers of ESP's were emphatic in stating that a properly maintained precipitator should not deteriorate over the expected life of the unit.¹⁴ Based on a review of all available information collected from both the industry and control device manufacturers, ESP systems were determined to be capable of meeting an emission limit of 0.10 g/dscm (0.044 gr/dscf) on a continuous, long-term basis.¹⁴

More recent information obtained from ESP manufacturers indicates that since the NSPS was promulgated, the industry has demanded further improvements to ensure continued compliance with PM emission limits associated with the NSPS or State permit requirements. Mills often require that ESP manufacturers provide emission limit guarantees such that the furnace can meet the permitted limit (e.g., 0.10 g/dscm [0.044 gr/dscf]) with only one

chamber of the ESP in operation. Two ESP manufacturers commonly guarantee that the permitted emission limit will not be exceeded while the recovery furnace is operating at 70 percent capacity with one chamber of the ESP in operation.^{4,6} Requests by mills for these types of guarantees began in the late 1980's and have resulted in the installation of ESP's that are sized to ensure that these emission limits are achieved continuously. This design provides mills with the advantage of being able to make ESP repairs to one chamber of the ESP without disrupting the operation of the furnace, and thus avoiding production losses while maintaining the integrity of the ESP. In addition, ESP's that meet these design criteria routinely achieve PM outlet emissions at levels less than or equal to half the NSPS (i.e., 0.050 g/dscm [0.022 gr/dscf]) under normal operating conditions.⁴

The information supplied by manufacturers is supported by long-term PM emission test data for recovery furnace ESP's supplied by the State of Washington.¹³ Figures 3-2 through 3-4 show monthly PM emission data for two kraft NDCE recovery furnaces with older ESP's over a 6-year period from 1988 to 1994 and one kraft NDCE recovery furnace with a newer ESP over a 5½-year period from 1990 to 1995. The figures provide an indication of concentrations achievable by older systems designed to meet the NSPS limits and by newer ESP's with improved design. The data also demonstrate the variability in ESP performance.

The data in Figure 3-2 were generated by an ESP of weighted-wire design that was designed to comply with a permit limit of 0.10 g/dscm (0.044 gr/dscf). The ESP was installed in 1974 and has a design and operating SCA of about 92 m²/(m³/sec) (467 ft²/1,000 acfm).¹⁵

The data in Figure 3-3 were generated by another ESP of weighted-wire design that was designed to comply with a permit limit of 0.10 g/dscm (0.044 gr/dscf). The recovery furnace was originally installed as a DCE recovery furnace in 1975 and converted to an NDCE recovery furnace in 1982.¹⁵ The ESP was last upgraded in 1982 and has a design and operating SCA of about 75 m²/(m³/sec) (383 ft²/1,000 acfm).¹⁵ The control system is

Figure 3-2. PM emission data for recovery furnace No. 3 at Mill A.

Figure 3-3. PM emission data for recovery furnace No. 4 at Mill B.

Figure 3-4. PM emission data for recovery furnace No. 3 at Mill B.

augmented with a combination low-energy venturi scrubber and packed-bed scrubber in series installed in 1984.¹⁵ The scrubbers provide some added PM removal and act as a heat-transfer unit to provide hot water.¹⁶

The data in Figures 3-2 and 3-3 indicate that although emissions are quite variable, these units can readily meet the NSPS limit of 0.10 g/dscm (0.044 gr/dscf) on a long-term, continuous basis.

Outlet PM emission concentrations at least as low as 0.002 g/dscm (0.001 gr/dscf) for recovery furnaces with newer ESP's have been documented in the Washington data as well as in the data provided by individual pulp mills.^{13,15} However, the ability of an ESP to maintain emissions on a continuous basis at levels substantially below 0.034 g/dscm (0.015 gr/dscf) has not been demonstrated.¹³ However, the data in Figure 3-4 do demonstrate that a system can readily meet a level of 0.034 g/dscm (0.015 gr/dscf) on a long-term, continuous basis. These data were generated by an NDCE recovery furnace with a rigid electrode ESP followed by a packed-bed scrubber. The recovery furnace was originally installed as a DCE recovery furnace in 1956 and converted to an NDCE recovery furnace in 1981.¹⁵ Both the ESP and the scrubber were installed in 1989.¹⁵

While the data in Figure 3-4 for recovery furnace No. 3 at Mill B are somewhat variable, they show considerably less variability and consistently lower emissions (less than 0.034 g/dscm [0.015 gr/dscf]) than the data associated with the two older ESP's. The ESP on recovery furnace No. 3 at Mill B was designed to achieve an outlet concentration of 0.069 g/dscm (0.033 gr/dscf). Furthermore, although the system was designed with an SCA of 79 m²/(m³/sec) (400 ft²/1,000 acfm), the furnace has operated at about 60 to 70 percent capacity over its life.¹⁶ Consequently, the operating SCA of the unit is estimated to be in the range of 110 to 130 m²/(m³/sec) (570 to 670 ft²/1,000 acfm) or 120 m²/(m³/sec) (620 ft²/1,000 acfm), on average. These data demonstrate that systems comprising a recent ESP with an SCA of about 120 m²/(m³/sec) (620 ft²/1,000 acfm) followed by a packed-

bed scrubber can achieve a maximum outlet concentration of 0.034 g/dscm (0.015 gr/dscf) on a long-term, continuous basis.

No single parameter in and of itself is a good predictor of ESP performance. Both the design of the ESP and operating variables affect the performance of the ESP. Although the SCA may provide some indication of the expected efficiency of the ESP, other design features, such as the location of the rappers and plate spacing (which differs from one ESP manufacturer to another), also affect the ESP's performance. For example, differences in plate spacing from one manufacturer to another have resulted in different manufacturers requiring different SCA's for the same outlet PM concentration.^{2,4} Another factor that complicates assessment of the effect of SCA on performance is that the PM emission concentrations for newer ESP's may be measured based on gas flow through one chamber with the recovery furnace operating at about 70 percent capacity.⁴ The mechanism used to report emissions and calculate the SCA (i.e., based on gas flow at 70 or 100 percent capacity) can mask any relationship between the SCA and PM emissions.⁴ Consequently, available data for recovery furnaces show only a limited relationship between outlet concentration and SCA.

The power input to the ESP can be a useful parameter in monitoring ESP performance. The value of the power input for each field and for the total ESP indicates how much work is being done to collect the PM. The power supply to the ESP consists of four basic components: (1) a step-up transformer (to step up the line voltage), (2) a high-voltage rectifier (to convert alternating current [a.c.] voltage to direct current [d.c.]), (3) a control element, and (4) a control system sensor.¹⁷ Most ESP's installed since the 1980's are equipped with primary voltage and current meters on the low-voltage (a.c.) side of the transformer and secondary voltage and current meters on the high-voltage rectifier (d.c.) side of the transformer.¹⁷ The power input for each transformer-rectifier (T-R) set is calculated by multiplying the voltage and current values of either the primary or secondary side of the transformer. The ESP control system is

designed to provide the highest possible voltage without causing sustained sparking between the discharge electrode and the collection surface. Spark meters can be used to set the maximum voltage/current levels for efficient operation. When the resistivity of the particulate is normal to moderately high, ESP performance improves as the total power input increases. However, when particulate resistivity is either low or very high or when spark rates are very high, improving the performance of the ESP may require decreasing the power input.¹⁷ In addition, newer, high-efficiency ESP's that are generously sized and sectionalized are relatively unaffected by changes in power input. The normal power input of some of these newer and larger ESP's may be reduced by one-half to two-thirds without substantially affecting performance.¹⁷ Therefore, power input cannot be used as a sole indicator of ESP performance.

Other operating variables that reportedly impact the performance of the ESP include temperature of the flue gas and maintenance practices. When flue gas temperatures exceed 260°C (500°F), the ESP's PM collection efficiency starts to decline. At low temperatures (less than 150°C [300°F]), the ESP may perform as desired, but corrosion will be accelerated (due to condensation of acid gases).⁴ To obtain optimal control on a continuous basis, the system should be operated within this temperature envelope.

Poor operating and maintenance practices may also result in a decline in ESP performance, and differences in operating and maintenance practices are expected to contribute to the variability in emissions from mill to mill and over time at the same mill. Repairs (e.g., replacing broken wires) are often delayed, and routine on-line maintenance is sometimes neglected. Mills commonly solicit bids for maintenance and repair work from ESP manufacturers and contracting firms that provide ESP maintenance services.⁴

3.1.1.2.2 Lime kilns. Although venturi scrubbers have traditionally been the most common PM control device used on kraft lime kilns, the use of ESP's to control PM emissions from

lime kilns has steadily increased since about 1980. The ESP is generally mounted on top of the lime kiln feed building, and the captured dry PM is rerouted to the kiln by gravity feed.¹⁸ The trend towards ESP's as PM control devices at new lime kiln installations and as replacement control devices for older scrubbers is primarily related to the lower energy costs, reduced maintenance, and increased reliability of the ESP's in comparison to venturi scrubbers that provide equivalent control. An added benefit is that lime kiln ESP's produce a dry product that can be recycled directly to the kiln. The wastewater produced by the venturi scrubber is typically recycled to the mud washers before the kiln to recover the lime particulate in the spent scrubbing fluid. Additional energy is needed to remove the excess water in the lime mud filter and to complete evaporation in the kiln. (Additional information about venturi scrubbers is provided in Section 3.1.2.2.)

The NSPS for kraft lime kilns requires that PM emissions from gas-fired and oil-fired lime kilns constructed, reconstructed, or modified after September 24, 1976 be less than or equal to 0.15 and 0.30 g/dscm (0.067 and 0.13 gr/dscf), respectively.^{10,11} Based on installation dates, approximately 28 percent of existing lime kilns are subject to the NSPS.¹

The PM emissions reported by the industry for lime kiln ESP's show less variability month to month and kiln to kiln than those associated with recovery furnace ESP's. Point-in-time PM data were reported for nine facilities with ESP's controlling lime kilns subject to the NSPS; these PM data showed outlet concentrations ranging from 0.0057 to 0.059 g/dscm (0.0025 to 0.026 gr/dscf).¹⁵

These reported data are confirmed by monthly PM emission data from the State of Washington for two gas-fired lime kilns with ESP's at Mills C and D.¹³ Both kilns are subject to the NSPS; the ESP's at Mills C and D were installed in 1982 and 1985, respectively.¹⁵

As shown in Figure 3-5, the PM emission data from the kiln at Mill C vary from 0.0025 to 0.0519 g/dscm (0.0011 to

Figure 3-5. PM emission data for lime kiln No. 5 at Mill C.

0.0227 gr/dscf) during the period from November 1988 to April 1996. The SCA of the ESP on this lime kiln is $90 \text{ m}^2/(\text{m}^3/\text{sec})$ ($460 \text{ ft}^2/1,000 \text{ acfm}$).¹⁵ The data for Mill C confirm that ESP's on existing lime kilns can readily meet the NSPS limit of 0.15 g/dscm (0.067 gr/dscf) on a long-term, continuous basis.

The lime kiln at Mill D (shown in Figure 3-6) consistently emitted PM at or below 0.018 g/dscm (0.008 gr/dscf) during the 7-year period from March 1989 to April 1996. The SCA for the lime kiln ESP at Mill D is $220 \text{ m}^2/(\text{m}^3/\text{sec})$ ($1,120 \text{ ft}^2/1,000 \text{ acfm}$).¹⁵ The monthly PM emission data from Mill D demonstrate that new ESP's on lime kilns can achieve a maximum outlet concentration of 0.023 g/dscm (0.010 gr/dscf) on a long-term, continuous basis.

3.1.2 Wet Scrubbers

The following discussion focuses on the control of gaseous HAP emissions using packed-bed scrubbers and PM HAP emissions using venturi scrubbers. Section 3.1.2.1 discusses packed-bed scrubbers as the primary mechanism of HCl control; the control of gaseous organic HAP's by packed-bed systems will also be discussed. Section 3.1.2.2 discusses venturi scrubbers as a means of controlling PM emissions. In addition to venturi scrubbers, the pulp and paper industry uses other types of wet scrubbers, such as impingement plate, cyclone, flooded disc, and packed-bed, to control PM emissions from lime kilns and SDT's. However, venturi scrubbers are the most prevalent type of wet scrubber used to control PM from these sources, and the other scrubber types do not control PM emissions more effectively than venturi scrubbers.

3.1.2.1 Packed-Bed Scrubbers. Test data indicate that both NDCE and DCE kraft recovery furnaces emit HCl in the furnace exhaust gas at concentrations as high as 100 parts per million by volume (ppmv), corrected to 8 percent O_2 .^{19,20} These exhaust streams also contain SO_2 at concentrations as high as 979 ppmv, corrected to 8 percent O_2 .^{1,19} Typically, facilities that use add-on control measures for acid gas emissions use packed-bed wet

Figure 3-6. PM emission data for lime kiln No. 1 at Mill D.

scrubbers. Although the packed-bed scrubbers on kraft recovery furnaces are not specifically designed to reduce HCl emissions, HCl control can be achieved as an ancillary benefit.

This section focuses on control of gaseous HCl emissions with packed-bed scrubbers. Packed-bed systems have been installed to a limited extent on kraft recovery furnaces for a variety of reasons, including acid gas (i.e., SO₂) control and hot-water generation (i.e., to recover heat from the flue gas).^{21,22} They have also been demonstrated to achieve high levels of HCl control on other combustion systems. The remainder of the section describes packed-bed scrubbing systems, presents a brief summary of the basic operating principles of packed-bed systems and their theoretical performance for both HCl and SO₂ emission reductions, examines packed-bed scrubber performance data for kraft recovery furnaces and for other combustion sources, and discusses existing packed-bed scrubber applications for recovery furnaces.

3.1.2.1.1 Description. As illustrated in Figure 3-7, the recovery furnace exhaust gases are ducted to the acid gas control system after PM has been removed in the ESP. Acid gas scrubbers control HCl and SO₂ emissions by mass transfer of these pollutants from the exhaust gas stream to a liquid scrubbing solution, typically either water or a caustic solution with water. Packed-bed scrubbers are the most frequently used absorption device because they provide excellent liquid-gas contact, leading to efficient mass transfer.^{23,24}

Schematics of two standard types of packed-bed scrubbers, the counter-flow design and the cross-flow design, are shown in Figures 3-8 and 3-9. Typically, the gases pass through a quench section before entering the scrubber to saturate the gas stream. The gases then enter the inlet plenum, which is designed to distribute the gases uniformly across the bed cross-section. As the gases flow through the bed, they contact a liquid film created by a flowing liquid that is distributed evenly throughout the bed. After the gas stream exits the bed, it passes through a mist eliminator to remove entrained droplets that may contain

Figure 3-7. Acid gas control system configuration on recovery furnace exhaust gases.

Figure 3-8. Schematic of a counterflow packed-bed scrubber.

Figure 3-9. Schematic of a cross-flow packed-bed scrubber.

alkaline salts (generated as the acid gases are scrubbed from the exhaust gas), residual absorbed acids, and PM that was not removed by the ESP or the packed bed. The paragraphs below describe the role of the packing and the scrubbing liquid in more detail.

A packed-bed scrubber is filled with packing material that is used to produce a large liquid film surface area for contact between the gas stream and scrubbing liquid. Packing materials are available in a variety of forms and materials, each having specific characteristics with respect to surface area, pressure drop, weight, corrosion resistance, and cost.²⁵ Specific packing materials are selected by the manufacturer to conform with the gas and liquid stream properties of a particular application. The gas stream moves through the packed bed, contacting the liquid film on the surface of the packing. In the counterflow configuration, the gas moves upward, while the liquid moves downward through the packed-bed section. In a cross-flow configuration, the gas moves in a horizontal direction, perpendicular to the liquid stream, which moves downward through the packing. The countercurrent system is more efficient for acid gas removal, but height limitations or particle loadings that can lead to plugging sometimes dictate use of the cross-flow configuration.²⁶

An aqueous scrubbing solution, which may be either water or an alkaline solution, is used in acid gas scrubbers. Because HCl is highly soluble in water, adequate control can often be achieved with water alone. However, because the exhaust from kraft recovery furnaces also contains SO₂, alkaline solutions are expected to be used for this source. In addition to providing substantially better SO₂ control and somewhat better HCl control, an alkaline solution typically is used to maintain a constant scrubber liquid pH at or slightly below 7.0 to prevent both scale buildup and corrosion of scrubber components. The scrubbing liquid that is expected to be used for acid gas control is caustic solution (sodium hydroxide [NaOH]), although sodium carbonate (Na₂CO₃) and calcium hydroxide (Ca[OH]₂) (slaked lime)

also can be used. When the acid gases are absorbed into the scrubbing solution, they react with alkaline compounds to produce neutral salts. The rate of absorption of the acid gases is dependent on the solubility of the acid gases in the scrubbing liquid. The neutralization reactions are essentially stoichiometric, i.e., the stoichiometric ratio of alkaline compounds added to the system to that required for complete neutralization of the acid absorbed into the scrubber solution is essentially 1:1 in packed-bed scrubbers.²⁶

3.1.2.1.2 Theoretical performance of packed-bed scrubbers.

Packed-bed scrubbers are chemical engineering unit operations that provide mass transfer between a soluble gas component (in the case of kraft recovery furnaces, HCl, SO₂, and possibly some organic HAP's) and a solvent liquid scrubbing solution (water or an alkaline solution). The driving force for absorption is the difference between the partial pressure of the soluble compound in the gas mixture and the vapor pressure of the solute gas in the liquid film in contact with the gas.²⁷ The performance of the system is a function of the mass transfer rate of the pollutant from the gas to the liquid solute and of the contact time between the gas and the liquid. These properties form the basis for the design equations that are typically used to characterize the theoretical performance of gas absorption systems like packed-bed scrubbers.

Because the pollutant concentration in the gas stream is very dilute, several assumptions that simplify these design equations considerably are reasonable. The waste gas is assumed to operate as an ideal gas; the scrubbing solution is assumed to be an ideal solution; heat effects associated with absorption are assumed to be negligible; and the reaction of the HCl and SO₂ with the alkaline material in the scrubbing solution is assumed to be fast compared to the rate-limiting absorption step. Also, because equilibrium characteristics of a counterflow scrubber are much less complex mathematically than the characteristics of a cross-flow tower, the theoretical analyses focus on the counterflow tower.

The design and performance equations for counterflow packed-bed scrubbers are based on the Whitman two-film theory, which is described in detail in reference 28.²⁸ The key element of this theory for the analysis of kraft recovery furnace packed-bed scrubbers is that the system is considered to be gas-film controlling or liquid-film controlling, depending on the pollutant to be controlled and the scrubbing liquid. For the recovery furnace exhaust stream, HCl absorption is liquid-film controlling, while both the liquid film and the gas film provide appreciable resistance to SO₂ absorption.²⁸ These system properties simplify the theoretical assessment of the performance of the system for HCl in that only gas-phase transfer needs to be considered. They also partially explain the difference in performance of packed-bed scrubbers for SO₂ and HCl.

An estimate of the theoretical performance of a packed-bed scrubber for HCl emissions can be developed by manipulating the system design equations.²⁹⁻³¹ For a specific set of inlet conditions, these design equations can be modified to obtain the following expression for the efficiency of a packed-bed scrubber:

$$\begin{aligned} \text{Eff} &= 1 - y_o / y_i \\ &= 1 - \exp(-Z / H_{OG}) \end{aligned}$$

where y_o is the outlet gas mole fraction, y_i is the inlet gas mole fraction, Z is the packing height, and H_{OG} is the height of a gas transfer unit.

These theoretical analyses have two important implications for the performance of packed-bed scrubbers in controlling HCl emissions from kraft recovery furnaces. First, the theoretical efficiency of the system is limited by the concentration that can be achieved in the exhaust gas from the scrubber when it is in equilibrium with the scrubber liquor feed. At the concentrations found in kraft furnace recovery exhaust gases and scrubbers, the Henry's Law coefficient is of the order of 10^{-3} or less.³² If the scrubber liquor feed is maintained at a pH of 6.5 or greater, the molar concentration of HCl in the feed is on the order of

6×10^{-9} . Theoretically, the limiting HCl concentration in the exhaust gas is well below 1 ppm. However, this theoretical limit is based only on ideal mass transfer considerations and does not address nonuniformities in gas and liquid flows that may be found in operating systems.

Second, if for a given system, the height of a transfer unit changes between pollutants by a factor of k , the penetration (i.e., $1 - \text{efficiency}$) for the two pollutants changes exponentially with $1/k$. The reported range of manufacturer's H_{OG} for plastic packings is 0.18 to 0.33 meters (m) (0.6 to 1.1 feet [ft]) for water as a scrubbing liquid and 0.15 to 0.31 m (0.5 to 0.7 ft) for caustic as a scrubbing liquid.²⁹ Note that the same reference reports a range of 0.15 to 0.61 m (0.7 to 2.0 ft) for scrubbing SO_2 with caustic. These data indicate that the height of a transfer unit for SO_2 is 2 to 3 times that for HCl, so that the penetration for SO_2 will be the square root or the cube root of that for HCl or, equivalently, that the penetration for HCl will be the square or the cube of the penetration for SO_2 . For example, if a system achieves 99 percent control for HCl, (i.e., the penetration is 0.01), the control efficiency for SO_2 would be expected to be in the range of 78 to 90 percent.

3.1.2.1.3 Performance of HCl scrubbers for kraft recovery furnaces. To provide a basis for subsequent analyses of HCl performance potential, a typical sample of emission test data on HCl concentrations and kraft recovery furnace combustion gas characteristics is compiled in Table 3-3. The emission test data are taken from tests conducted in 1992-93 by the National Council of the Paper Industry for Air and Stream Improvement, Inc. (NCASI).¹⁹ A complete compilation of available HCl emission test data for kraft recovery furnaces is presented in a separate memorandum.³³ The data in Table 3-3 reflect two factors that complicate the design, operation, and characterization of performance of packed-bed scrubbing systems--the relatively large flue gas flow rates generated by these systems and the relatively low and variable concentrations of both HCl and SO_2 generated by these systems. Because of the large flow rates, either large-

TABLE 3-3. SUMMARY OF DATA ON KRAFT RECOVERY FURNACE COMBUSTION GAS CHARACTERISTICS¹⁹

Mill code	Furnace no.	Furnace type	BLS fired, million kg/d (million lb/d)	%Cl in BLS fired	Flue gas flow rate, dscmm (dscfm)	Stack O ₂ , %	Flue gas concentrations ^a		
							ppm HCl @ 8% O ₂	ppm SO ₂ @ 8% O ₂	ppm CO @ 8% O ₂
AA	1	NDCE	1.51 (3.32)	0.43	3,766 (132,994)	3.1	44.0	224.1	41.8
AA	9	DCE	1.18 (2.61)	0.36	4,352 (153,705)	6.6	5.9	60.0	40.9
BB	3	DCE	0.87 (1.92)	1.35	2,575 (90,970)	5.2	30.2	115.9	NM
BB	4	NDCE	1.32 (2.90)	1.29	4,479 (158,180)	5.6	0.5	0.5	NM
CC	2	NDCE	0.37 (0.82)	0.45	1,349 (47,652)	10.5	36.2	273.2	42.4
CC	3	NDCE	1.32 (2.90)	0.44	4,269 (150,772)	7.3	48.4	322.2	38.6
DD	4	NDCE	1.76 (3.89)	1.05	4,378 (154,610)	2.8	0.8	0.1	NM
EE	6	DCE	0.84 (1.86)	1.04	3,024 (106,785)	8.3	19.9	66.5	NM
EE	7	DCE	0.70 (1.55)	1.09	2,621 (92,569)	7.5	8.1	13.1	NM
FF	2	NDCE	0.68 (1.51)	1.06	1,872 (66,110)	8.8	4.3	7.1	NM
FF	3	NDCE	0.80 (1.77)	0.96	1,988 (70,204)	7.6	0.2	ND	NM
FF	4	NDCE	2.01 (4.43)	1.10	4,102 (144,847)	4.7	0.1	ND	NM
GG	10	NDCE	0.89 (1.97)	0.61	3,338 (117,869)	5.4	24.1	29.7	112.7
HH	3	NDCE	1.08 (2.38)	0.63	4,027 (142,222)	11.0	40.8	61.5	NM

^aIn all cases emissions given are average values from two to six consecutive tests.

BLS - black liquor solids.

dscmm - dry standard cubic meters per minute.

dscfm - dry standard cubic feet per minute.

NM - not measured.

ND - not detected.

diameter scrubbers or parallel systems are needed to maintain proper flow conditions in the scrubber. The low HCl concentrations such as those in Table 3-3 are reported to affect the ability of the scrubber to achieve high removal efficiencies because of limitations on the outlet concentrations that can be achieved with the systems.^{23,34}

Only limited test data on acid gas control with packed-bed scrubbers are available for kraft recovery furnaces. However, packed-bed scrubbers are used widely on waste combustion systems, and a substantial body of information is available on their performance for these systems. These data show that these scrubbers can achieve removal efficiencies of 99 percent or greater with relatively high concentrations of HCl. Efficiencies of this order are confirmed by scrubber manufacturer representatives, who indicate that properly designed and operated packed-bed scrubbers can achieve HCl emission reductions of at least 99 percent or an HCl outlet concentration not exceeding 5 ppmv for recovery furnace exhaust streams.^{23,34}

Available data on scrubber performance are presented in Table 3-4 for seven kraft DCE and NDCE recovery furnaces and five medical waste incinerators (MWI's).^{15,21,22,35,36} With one exception, the data in Table 3-4 indicate that packed-bed scrubbers on waste combustion systems can achieve HCl removal efficiencies of 98.8 percent or greater. The one exception is a cross-flow scrubber, which manufacturers indicate are less efficient than counterflow systems. The high HCl removal efficiencies with packed-bed scrubbers are supported by a summary of trial burn data for hazardous waste incinerators (HWI's).³⁷ This study contains limited data on HCl control efficiencies for 10 HWI's based on feed rates of organic chlorine to the system and outlet HCl measurements.³⁷ Because the reported HWI data are insufficient to characterize inlet concentrations or scrubber characteristics, they were excluded from Table 3-4. However, efficiencies for all 10 systems are greater than 98 percent, and 6 of the 10 systems showed efficiencies of substantially greater than 99 percent.³⁷ More detailed data on two of these systems

TABLE 3-4. SUMMARY OF ACID GAS SCRUBBER PERFORMANCE DATA^{15, 21, 22, 35, 36}

Type of facility	Wet scrubber description	Inlet gas flow, acmm (acfm)	L/G ratio, L/acm (gal/10 ³ acf)	HCl performance data			SO ₂ performance data		
				Inlet conc. (ppmv) ^a	Outlet conc. (ppmv) ^a	Efficiency (%)	Inlet conc. (ppmv) ^a	Outlet conc. (ppmv) ^a	Efficiency (%)
NDCE recovery furnace	ESP followed by packed-bed scrubber with 2 cross-flow packed beds separated by spray chamber	3,540 (125,000)	2.1-2.8 (16-21)	NA	NA	NA	150 ^b	2.5 ^b	98
				NA	NA	NA	NA	0.08	NA
NDCE recovery furnace	ESP followed by venturi scrubber and cross-flow packed-bed scrubber with 3 sections	4,960 (175,000)	1.7-2.3 (13-17)	NA	NA	NA	NA	0.22	NA
DCE recovery furnace	ESP followed by packed-bed scrubber with process water	7,360 (260,000)	1.5-2.0 (12-15)	NA	NA	NA	NA	10-20	NA
3 DCE recovery furnaces	2 ESP's serving 3 recovery furnaces followed by 1 spray tower/packed-bed scrubber with caustic/water	14,800 (522,049)	NA	NA	NA	NA	NA	<1	NA
DCE recovery furnace	ESP followed by packed-bed scrubber with sodium hydroxide/water	9,200 (325,000)	2.9 (22)	NA	NA	NA	NA	56-64	NA
MWI	Venturi scrubber followed by 2 packed-bed scrubbers	270 (9,600)	3.7-4.0 (28-30)	1,160	1.38	99.9	1.5	0.6	77.5
MWI	Baghouse followed by cross-flow packed-bed scrubber	65 (2,300)	3.2 (24)	198	44	85.8 ^c	21.5	2.2	80
MWI	Venturi scrubber followed by packed-bed scrubber	180 (6,400)	0.75 (5.6)	1,160	6.3	99.3	NA	NA	NA
MWI	Venturi scrubber followed by packed-bed scrubber	63 (2,300)	3.7 (28)	1,280	15.1	98.8	7.3	≈0.3	>90
MWI	Venturi scrubber followed by packed-bed scrubber	91 (3,200)	2.1 (16)	1,356	0.7	99.9	53.7	<0.4	>99.9

^aMWI data corrected to 7 percent O₂; recovery furnace data corrected to 8 percent O₂.

^bDesign criteria; actual outlet SO₂ equals 0.08 ppm.

^cThis efficiency may be biased low due to plugged nozzles during the test.

acmm = actual cubic meters per minute.

acfm = actual cubic feet per minute.

L/acm = liters per actual cubic meter.

gal/10³ acf = gallons per thousand actual cubic feet.

ppmv = parts per million volume.

that used a caustic scrubbing solution showed outlet concentrations of 1.3 and 13 ppmv, with removal efficiencies of >99.9 percent and 98.2 percent, respectively.³⁸ Taken together, the data in Table 3-4 and the HWI data show that a properly designed and operated packed-bed scrubber can achieve HCl removal efficiencies in the range of 99 percent.

For two MWI systems in Table 3-4, outlet HCl concentrations of less than 1.5 ppmv were obtained with HCl inlet concentrations of greater than 1,000 ppmv. This same type of reduction appears to have been achieved by the one HWI system with an outlet concentration of 1.3 ppmv. These MWI and HWI data support the results from the theoretical analyses on the ability of these systems to achieve low outlet concentrations. Also, systems with caustic scrubbing solution are able to achieve outlet concentrations not exceeding 5 ppmv.^{23,34}

3.1.2.1.4 Performance data--gaseous organic HAP's. Data were presented in Chapter 2 on levels of gaseous organic HAP emissions expected from recovery furnaces. While there are no available gaseous organic HAP emission test data that would allow the determination of the performance of packed-bed scrubbers in controlling HAP emissions from recovery furnaces, packed-bed scrubbers designed primarily for HCl control would be expected to control emissions of the water-soluble gaseous organic HAP's (such as methanol and formaldehyde) to a limited degree. However, because of the low concentrations of gaseous organic HAP's expected in the furnace exhaust streams, absorption of these pollutants may be limited in packed-bed scrubbers designed for HCl control due to the small concentration gradient (driving force) between the gas and scrubbing liquid.

In providing design and cost information for packed-bed scrubbers for HCl control, vendors were asked to provide estimates of the degree to which the HAP's methanol, formaldehyde, and acetaldehyde would be controlled with the same equipment. One vendor estimated removal efficiencies of 50 percent for methanol and formaldehyde and 20 percent for acetaldehyde but would not offer a performance guarantee for the

three pollutants.³⁴ While the packed-bed scrubber may remove some gaseous organic HAP's from the gas stream, a portion of the pollutants absorbed into the scrubbing fluid may volatilize back into the atmosphere from the wastewater treatment process, which would decrease the overall system removal efficiencies. Currently, data are insufficient to determine whether the blowdown of the scrubber liquor is sufficient to maintain low levels of HAP's in the scrubber water to maintain the concentration gradient and to prevent stripping.

3.1.2.1.5 Existing applications of packed-bed scrubbers. Currently, two NDCE recovery furnaces, both at the same kraft pulp mill, are each equipped with a cross-flow packed-bed scrubber that operates downstream from an ESP. For other recovery furnace applications, the packed-bed scrubber also would be installed downstream from the PM control device, which would remove over 99 percent of the PM from the emission stream before scrubbing.

One of the packed-bed scrubbers currently in operation on an NDCE recovery furnace was designed for SO₂ control and hot-water generation (i.e., to recover heat from the flue gas).^{21,22} Fresh water is used as the scrubbing medium, with some added caustic. Although no HCl emission data are available for the recovery furnaces at this mill, SO₂ scrubber design criteria are available for this recovery furnace. As shown in Table 3-4, the design inlet SO₂ concentration was 150 ppmv, while the design outlet SO₂ concentration was 2.5 ppmv, for a design SO₂ emission reduction of 98 percent.³⁵ Because HCl is more soluble in water than SO₂ and based on the theoretical discussion presented earlier, HCl emission reductions greater than 98 percent would be expected for this packed-bed scrubber.

While only one facility has installed packed-bed scrubbers on NDCE recovery furnaces, three other facilities have reported that packed-tower systems are being used to control emissions from five DCE recovery furnaces.¹⁵ Although no information is available on the control of HCl achieved by these systems, the available data indicate that they achieve SO₂ outlet

concentrations ranging from <1 to about 60 ppmv.¹⁵ Furthermore, the data indicate that the three packed-tower systems handle flow rates in the range of 7,360 to 14,800 actual cubic meters per minute (acmm) (260,000 to 522,000 acfm).¹⁵ These systems show that counterflow packed-tower systems are compatible with both DCE and NDCE recovery furnace exhaust streams and provide a viable technology for control of HCl emissions from these furnaces.

3.1.2.2 Venturi Scrubbers. Venturi scrubbers are a demonstrated control technology for reducing PM emissions and, therefore, PM HAP emissions from lime kilns and SDT's. Particulate matter emissions from approximately 86 percent of lime kilns and 35 percent of SDT's are controlled using venturi scrubbers.¹ However, venturi scrubbers are used on only one existing recovery furnace (an NDCE recovery furnace) as the sole PM control device.¹² Venturi scrubbers may also provide, to a more limited extent, control of gaseous HAP emissions. This section briefly describes venturi scrubbers and presents PM HAP performance data.

3.1.2.2.1 Description. Venturi scrubbers are designed to remove PM primarily by impaction through high-energy contact between the scrubbing liquid and suspended PM in the gas stream.²⁶ A schematic of a venturi scrubbing system is shown in Figure 3-10. A venturi scrubbing system typically consists of a venturi scrubbing vessel and cyclonic separator. The venturi scrubbing vessel has a converging section, a throat section, and diverging section.

The exhaust gas enters the converging section and, as the cross-sectional area of the scrubber vessel decreases, gas velocity increases. Scrubbing liquid is introduced either at the entrance to the converging section or at the throat.³⁹ The exhaust gas, which is pulled through the venturi vessel by the system's induced draft fan and forced to move at extremely high velocities in the throat, shears the scrubbing liquid from the walls, atomizing the liquid.^{26,39} Particulate matter and gaseous pollutants are transferred from the gas stream to the liquid

Figure 3-10. Schematic of a venturi scrubber.

droplets via impaction and diffusive mass transfer in the throat section as the exhaust stream turbulently mixes with the atomized scrubbing liquid. The throat section may be constructed so that the size of the throat opening is adjustable. With an adjustable-throat (or variable-throat) venturi, the gas velocity across the throat can be maintained at a constant speed as the gas flow rate changes, thereby maintaining the desired PM collection efficiency. From the throat section, the exhaust stream passes through the diverging section of the venturi scrubbing vessel, where the velocity decreases. Diffusion, which is an effective collection mechanism for fine particles and also the primary mechanism of gaseous pollutants transfer, usually occurs in the diverging section, where the velocities of the gas stream and liquid droplets are almost equal. Collection of fine particles by the liquid droplets is possible because the path of fine particles is influenced primarily by Brownian motion rather than by the path of the gas stream.⁴⁰

An entrainment separator, typically a cyclonic separator, is needed to collect the PM entrained in the droplets because the high velocity of the exhaust stream from the venturi scrubbing vessel would have a tendency to exhaust the droplets.³⁹

3.1.2.2.2 Performance data--PM HAP's. Available information indicates that control systems that achieve the greatest total PM collection efficiencies also achieve the best performance for PM HAP emissions.⁸ Thus, although the following information is presented in terms of total PM, the relative performance of the different systems is applicable to that portion of the total PM that is comprised of PM HAP's.

The performance of the scrubber in terms of PM collection is strongly affected by the pressure drop across the scrubber throat, the liquid-to-gas (L/G) ratio, and the particle size distribution. Particulate matter collection efficiency generally increases as the throat velocity and turbulence of the gas stream increase, as indicated by an increased pressure drop across the scrubber.

Typical venturi scrubber L/G ratios for PM control range from 0.4 to 1.3 liters per actual cubic meter (L/acm) (3 to 10 gallons per 1,000 actual cubic feet [gal/10³ acf]). While L/G ratios up to 2.7 L/acm (20 gal/10³ acf) can be used, increasing the L/G ratio beyond 1.3 L/acm (10 gal/10³ acf) usually does not significantly improve PM collection efficiency. However, venturi scrubbers with L/G ratios ranging from 2.7 to 5.3 L/acm (20 to 40 gal/10³ acf) are used where absorption of gaseous pollutants in addition to PM control is desired. Liquid-to-gas ratios below 0.4 L/acm (3 gal/10³ acf) are usually not sufficient to cover the throat section.³⁹

For lime kiln applications, PM collection efficiencies for venturi scrubbers average 99 percent.³⁹ These results are supported by data reported for four lime kiln scrubbers.^{15,41} One scrubber provided a removal efficiency of 98 percent with a pressure drop of 26 millimeters of mercury (mm Hg) (14 inches of water [in. H₂O]).⁴¹ The other three scrubbers provided removal efficiencies of greater than 99.5 percent with scrubber pressure drops in the range of 37 to 45 mm Hg (20 to 24 in. H₂O).¹⁵

Variable-throat venturi scrubbers with pressure drops that range from 19 to 56 mm Hg (10 to 30 in. H₂O) and average 37 mm Hg (20 in. H₂O) are typically used for controlling PM emissions from lime kilns.^{1,40} Typical L/G ratios are between 1.3 and 2.7 L/acm (10 and 20 gal/10³ acf).⁴⁰ Particle size distribution data, based on limited lime kiln test data, show that approximately 17 percent of the particles entering the scrubber are less than 10 micrometers (μm) in diameter, while 98 percent of particles exiting the scrubber are less than 10 μm in diameter.⁴² Lime mud with a high soda content, which results from inefficient washing of the lime mud, can produce a large quantity of PM in the 0.1 to 1.0 μm size range.⁴⁰ Particles in this size range are the most difficult to remove and may require increased scrubber pressure drops or process modifications to improve lime mud washing.⁴⁰

The NSPS for kraft lime kilns requires that PM emissions from gas-fired and oil-fired lime kilns constructed, reconstructed, or modified after September 24, 1976 be less than

or equal to 0.15 and 0.30 g/dscm (0.067 and 0.13 gr/dscf), respectively.^{10,11} Based on installation dates, approximately 28 percent of existing lime kilns are subject to the NSPS.¹

Long-term PM data are available for two gas-fired lime kilns with venturi scrubbers that are subject to the NSPS PM limit of 0.15 g/dscm (0.067 gr/dscf). Figures 3-11 and 3-12 present monthly PM emission data from the State of Washington for lime kilns at Mills A and B over a 6-year period from 1988 to 1994.¹³ The lime kilns at Mills A and B were installed in 1980 and 1979, respectively.¹⁵ The data demonstrate that existing venturi scrubbers on lime kilns can readily meet the NSPS PM level of 0.15 g/dscm (0.067 gr/dscf) on a long-term, continuous basis.

For SDT applications, reported PM removal efficiencies for venturi scrubbers range from 97 to greater than 99 percent.^{40,42,43} The average pressure drop for SDT venturi scrubbers is 15 mm Hg (8 in. H₂O).¹ Liquid-to-gas ratios range from 1.0 to 1.3 L/acm (8 to 10 gal/10³ acf).⁴⁰ Weak wash (from the lime mud washer) is the scrubbing fluid for the majority of SDT venturi scrubbers.¹

The NSPS for kraft pulp mills require that PM emissions from SDT's that are constructed, modified, or reconstructed after September 24, 1976 be less than 0.10 kg/Mg (0.20 lb/ton) of BLS fired in the recovery furnace.^{10,11} Based on installation dates, approximately 29 percent of existing SDT's are subject to the NSPS.¹²

No long-term PM data are available for SDT's with venturi scrubbers that are subject to the NSPS limit of 0.10 kg/Mg (0.20 lb/ton) BLS. However, long-term data are available for two SDT's equipped with packed-bed scrubbers designed to meet a more stringent PM permit limit of 0.06 kg/Mg (0.12 lb/ton) BLS; high-efficiency venturi scrubbers are expected to achieve equivalent control. Figures 3-13 and 3-14 present monthly PM emission data from the State of Washington for two SDT's with packed-bed scrubber systems at Mill B over a 6-year period from 1988 to 1994.¹³ Figure 3-15 presents monthly PM emission data from the State of Washington for a new SDT with a combination venturi and

Figure 3-11. PM emission data for lime kiln at Mill A.

Figure 3-12. PM emission data for lime kiln No. 4 at Mill B.

Figure 3-13. PM emission data for SDT No. 3 at Mill B.

Figure 3-14. PM emission data for SDT No. 4 at Mill B.

Figure 3-15. PM emission data for SDT No. 22 at Mill C.

packed-bed scrubber system at Mill C over a 2-year period from 1992 to 1994.¹³ These data demonstrate that high-efficiency wet scrubbers on SDT's can achieve a maximum outlet PM level of 0.06 kg/Mg (0.12 lb/ton) BLS on a long-term, continuous basis.

3.1.3 BLO Control

As explained in Chapter 2, BLO systems that use pure oxygen instead of air to oxidize black liquor do not need a system vent because all of the oxygen is consumed in the oxidation reaction. As a result, there are no emission points for the molecular O₂ BLO unit. Black liquor oxidation systems that use air to oxidize black liquor require vents for each oxidation tank. Add-on controls currently used to reduce gaseous organic HAP emissions from air-sparging BLO units collect and incinerate exhaust gases from the BLO vents. This section describes the add-on controls and presents the reductions in gaseous organic HAP emissions that can be achieved with the add-on controls.

3.1.3.1 Description. Of the estimated 42 kraft mills with air-based BLO systems, two mills reduce gaseous organic HAP emissions from air-sparging BLO vents with vent gas collection/incineration systems. The BLO vent gas collection/incineration method used by one mill involves ducting the vent gases to two condensers in series (to remove water from the gases), reheating the gases, and then ducting the dry gases to a power boiler for incineration.^{44,45} The control method used by the second mill is identical except that a mesh-pad mist eliminator is used in place of the condensers to remove water from the vent gas.^{46,47} Both mills incinerate their BLO vent gases in order to reduce TRS emissions. Because gaseous organic HAP's such as methanol, acetaldehyde, and methyl ethyl ketone are also emitted from BLO vents, emissions of these HAP's would also be reduced by the incineration of BLO vent gases. Particulate HAP's and acid gases (e.g., HCl) are not emitted from BLO vents.

Before the BLO vent gases can be incinerated, they must first be captured and transported to the incineration device. Vent gases from a BLO unit can be hard-piped to the combustion control device. The type of duct material that can be used is

determined by the characteristics of the gas in the vent stream.⁴⁸ Two materials commonly used in the construction of vent ducts in the pulp and paper industry are fiberglass and stainless steel. Fiberglass ducts have the advantages of relatively low cost, light weight, and corrosion resistance, but are unable to be electrically grounded to prevent the buildup of static charge and the absorption of hydrocarbons in its fiberglass resin.⁴⁸ Stainless steel is the preferred material of construction for NCG transport systems.⁴⁹ Stainless steel has the advantage of resisting corrosion by water and sulfur compounds but is susceptible to corrosion by chlorides that may be present in a vent gas control system that includes other vents besides the BLO vent (e.g., bleach plant vent).⁵⁰

The BLO vent gas may be conditioned to alter the moisture content and/or the temperature of the stream before it is vented to the combustion control device. Condensers, knockout drums, or entrainment separators may be used to condition the gas in the gas transport system.⁴⁸

Vent gases are preheated only when emissions are controlled with a combustion device. Preheating is generally only practiced on high-volume, low-concentration (HVLC) streams, where the risk of explosion is sufficiently low.⁵¹ The vent gases from BLO units can be classified as HVLC streams. Power boilers and stand-alone thermal oxidizers are generally the preferred combustion devices for incinerating HVLC streams. Power boilers, which include coal, natural gas, oil, wood waste, or combination fuel-fired boilers, are designed to produce heat, steam, and electricity for pulp mill operations.⁴⁸ A thermal oxidizer is a refractory-lined chamber containing a burner or burners used to oxidize vent streams containing volatile organic compounds (VOC's).⁴⁸ Both combustion devices have been demonstrated in the pulp and paper industry as control devices for vent emissions.⁴⁸

Combustion control devices, such as power boilers and thermal oxidizers, destroy the chemical structure of organic compounds by oxidation at elevated temperatures. These devices operate on the principle that any VOC heated to a high enough

temperature in the presence of sufficient oxygen will oxidize to predominantly CO₂ and H₂O.⁵² Combustion devices such as power boilers and thermal oxidizers can achieve VOC/HAP destruction efficiencies of 98 percent or greater.^{53,54} Therefore, a net removal efficiency of 98 percent was assumed for all HAP's for the BLO incineration control system.

3.1.3.2 Performance data--gaseous organic HAP's. Because neither of the two vent gas collection/incineration systems currently existing has undergone emissions testing, the gaseous organic HAP emission reductions associated with a BLO vent gas control system were estimated based on gaseous organic HAP emission data available from uncontrolled air-sparging BLO systems, assuming a 98 percent destruction efficiency.⁵⁵ The gaseous organic HAP emission reductions resulting from BLO control are presented in Table 3-5. For a BLO unit with a BLS firing rate of 700,000 kilograms of BLS per day (kg BLS/d) (1.5 million pounds of BLS per day [lb BLS/d]) and 351 operating days per year (d/yr), controlling emissions from the BLO vent could reduce average gaseous organic HAP emissions by about 47 Mg/yr (54 ton/yr), of which methanol accounts for about 85 percent.

3.2 EQUIPMENT CHANGES/MODIFICATIONS

This section describes equipment changes/modifications that could be applied to recovery furnaces at kraft pulp and paper mills to reduce gaseous organic HAP emissions. The two equipment changes/modifications are elimination of black liquor or HAP-contaminated process water from ESP control systems and conversion from a DCE recovery furnace system to an NDCE recovery furnace, which are discussed in Sections 3.2.1 and 3.2.2, respectively.

3.2.1 Elimination of Black Liquor used in NDCE Recovery Furnace ESP Control Systems

When hot recovery furnace flue gases come in contact with ESP control systems, gaseous organic HAP's (primarily methanol) may be stripped from any black liquor or HAP-contaminated process water present in the system and emitted to the atmosphere.

TABLE 3-5. HAP EMISSIONS FOR BLO UNITS⁵⁵

Hazardous air pollutant	Uncontrolled BLO unit		Controlled BLO unit	
	Emission factor, mass/mass BLS	Mass rate, kg/yr (lb/yr) ^a	Emission factor, mass/mass BLS	Mass rate, kg/yr (lb/yr) ^a
Total organic HAP's ^b	2.03 x 10 ⁻⁴	48,500 (107,000)	4.06 x 10 ⁻⁶	969 (2,140)
Acetaldehyde	1.48 x 10 ⁻⁵	3,530 (7,790)	2.96 x 10 ⁻⁷	70.7 (156)
Benzene	1.21 x 10 ⁻⁶	289 (637)	2.42 x 10 ⁻⁸	5.78 (12.7)
Formaldehyde	2.89 x 10 ⁻⁷	69 (152)	5.78 x 10 ⁻⁹	1.38 (3.04)
Methanol	1.73 x 10 ⁻⁴	41,300 (91,100)	3.46 x 10 ⁻⁶	826 (1,820)
Methyl ethyl ketone	4.24 x 10 ⁻⁶	1,010 (2,230)	8.48 x 10 ⁻⁸	20.3 (44.6)
Methyl isobutyl ketone	1.77 x 10 ⁻⁶	423 (932)	3.54 x 10 ⁻⁸	8.45 (18.6)
Phenol	1.93 x 10 ⁻⁶	461 (1,020)	3.86 x 10 ⁻⁸	9.22 (20.3)
Toluene	1.44 x 10 ⁻⁶	344 (758)	2.88 x 10 ⁻⁸	6.88 (15.2)
Xylenes	4.28 x 10 ⁻⁶	1,020 (2,250)	8.56 x 10 ⁻⁸	20.4 (45.1)

^aMass rates are based on a BLS firing rate of 700,000 kg BLS/d (1.5 million lb BLS/d) and 351 operating d/yr.

^bTotal organic HAP's include all gaseous HAP's in this table. Numbers may not add exactly due to rounding.

Electrostatic precipitator control systems include the ESP plus the PM return system associated with the ESP. One method of controlling gaseous organic HAP emissions from ESP systems is to prevent their generation by eliminating the black liquor or contaminated process water from the system. This equipment modification for ESP's used with NDCE recovery furnaces and the associated HAP emission reductions are discussed below. (This equipment modification is not discussed as an option for reducing gaseous organic HAP's from DCE recovery furnaces because, as discussed in Chapter 2, no data are available to determine if eliminating the wet bottom ESP's that are typically used with DCE recovery furnaces would actually decrease overall gaseous organic HAP emissions.)

3.2.1.1 Description. Particulate matter emissions from approximately 23 percent of all NDCE recovery furnaces are controlled with wet-bottom ESP's that use either unoxidized black liquor or process water in the ESP bottom. The majority (77 percent) of NDCE recovery furnaces, however, are controlled with dry-bottom ESP's.¹ Unoxidized black liquor is used in about 87 percent of the wet-bottom ESP's on NDCE recovery furnaces, and water is used in the remaining 13 percent.

Since the 1980's, the industry trend has been toward the use of dry-bottom ESP's. Some mills that installed wet-bottom ESP's on NDCE recovery furnaces in the late 1970's and early 1980's experienced difficulties in meeting the NSPS TRS emission limit of 5 ppm. These mills attempted to comply with the TRS emission limit through the use of one of the following techniques:

(1) modifying the bottom of the ESP to limit contact between the flue gases and the black liquor (e.g., using baffles),
(2) switching from the use of black liquor to using water in the ESP bottom, or (3) converting from a wet-bottom ESP to a dry-bottom ESP. In general, technique Nos. 2 and 3 proved to be the most viable options for meeting the TRS emission limit on a continuous basis.^{56,57} Because the mechanism for generating TRS emissions in the wet-bottom ESP is the same mechanism for generating HAP emissions, technique Nos. 2 and 3 would also

prevent methanol and any other gaseous organic HAP's from being generated in the ESP, provided the water used in technique No. 2 is not contaminated with substantial quantities of organic compounds.

The major modifications involved in technique No. 3 (i.e., converting a wet-bottom ESP to the dry-bottom design) include (1) removing the existing agitator paddles and liquor piping, (2) installing a perpendicular drag scraper system, shallow fallout hoppers, drag chain conveyors, rotary valves, ash mixing tank, agitator, and associated instrumentation, and (3) making piping modifications.^{58,59}

The older design dry-bottom ESP control systems sometimes use black liquor to sluice and transport the PM captured by dry-bottom ESP's to the saltcake mix tank. As a result, gaseous organic HAP's may be stripped from the black liquor as the hot recovery furnace flue gases are pulled through the ESP by the induced draft fan. The gaseous organic HAP emissions could be controlled by converting to a dry PM return system. Dry PM return systems eliminate the use of black liquor in the PM return system, so that the captured PM does not contact any black liquor until it reaches the mix tank. These newer PM return systems also are equipped with rotary valves (through which the dry captured PM passes) that provide an air lock between the ESP and the remainder of the PM return system and the mix tank (which contains black liquor).⁶⁰ According to one ESP manufacturer, systems that included dry return of the captured PM were initially installed around 1985.⁶⁰

3.2.1.2 HAP Emission Reduction Potential. As shown in Table 3-6, the elimination of black liquor from ESP control systems results in substantial reductions for the majority of the gaseous organic HAP compounds. (Note: Although HCl emissions are included in Table 3-6, HCl emissions are unaffected by the presence or absence of black liquor in the ESP system.) Although the available data indicate that acetaldehyde emissions increase with the elimination of black liquor from ESP control systems,

TABLE 3-6. HAP EMISSIONS FOR NDCE RECOVERY FURNACES⁵⁵

Hazardous air pollutant	ESP control system with black liquor		ESP control system without black liquor		Percent reduction
	Emission factor, mass/mass BLS ^{a,b}	Mass rate, kg/yr (lb/yr) ^c	Emission factor, mass/mass BLS ^{b,d}	Mass rate, kg/yr (lb/yr) ^c	
Total organic HAP's ^e	1.30×10^{-4}	31,000 (68,400)	3.67×10^{-5}	8,760 (19,300)	72
Acetaldehyde	7.50×10^{-6}	1,790 (3,950)	1.52×10^{-5}	3,630 (8,000)	-103
Benzene	9.73×10^{-6}	2,320 (5,120)	1.73×10^{-6}	413 (911)	82
Formaldehyde	2.98×10^{-6}	712 (1,570)	1.93×10^{-6}	461 (1,020)	35
Methanol	5.04×10^{-5}	12,000 (26,500)	4.93×10^{-6}	1,180 (2,600)	90
Methyl ethyl ketone	7.46×10^{-6}	1,780 (3,930)	1.80×10^{-6}	430 (948)	76
Methyl isobutyl ketone	9.23×10^{-6}	2,200 (4,860)	2.27×10^{-6}	542 (1,200)	75
Phenol	1.50×10^{-5}	3,580 (7,900)	2.05×10^{-6}	490 (1,080)	86
Toluene	8.37×10^{-6}	2,000 (4,410)	2.03×10^{-6}	485 (1,070)	76
Xylenes	1.92×10^{-5}	4,590 (10,100)	4.76×10^{-6}	1,140 (2,510)	75
HCl	1.20×10^{-4}	28,700 (63,200)	1.20×10^{-4}	28,700 (63,200)	—

^aEmission factors for gaseous organic HAP's are based on the average emission factors for NDCE recovery furnaces equipped with wet-bottom ESP's or with dry-bottom ESP's with wet PM return systems.

^bEmission factor for HCl is based on the average emission factor for all NDCE recovery furnaces.

^cMass rates are based on a furnace size of 700,000 kg BLS/d (1.5 million lb BLS/d) and 351 operating d/yr.

^dEmission factors for gaseous organic HAP's are based on the average emission factors for NDCE recovery furnaces equipped with dry-bottom ESP's and dry PM return systems.

^eTotal organic HAP's include all gaseous HAP's in this table except HCl. Numbers may not add exactly due to rounding.

the difference in the acetaldehyde levels may be an anomaly of the limited data on acetaldehyde emissions.⁵⁵

Emission data are available for 10 NDCE recovery furnaces with black liquor in the ESP control system (i.e., 6 NDCE recovery furnaces with wet-bottom ESP's and 4 NDCE recovery furnaces with dry-bottom ESP's and wet PM return systems).⁵⁵ Emission data are also available for three NDCE recovery furnaces with dry-bottom ESP's that have dry return of the captured PM.⁵⁵ Figure 3-16 illustrates the differences in methanol emissions between the two data sets. The methanol emission data from the ten NDCE recovery furnaces with black liquor in the ESP control system are significantly higher than those from the three NDCE recovery furnaces with dry-bottom ESP's and dry PM return systems.

Based on the available emission test data, eliminating the black liquor from the ESP control system reduces total gaseous organic HAP emissions by approximately 72 percent.⁵⁵ In addition to their lower HAP emission potential, NDCE recovery furnaces with dry-bottom ESP's and dry PM return also have lower TRS emissions than NDCE recovery furnaces with black liquor in the ESP control system.¹⁵

For an NDCE recovery furnace with a furnace size of 700,000 kg BLS per day (1.5 million lb BLS per day) and 351 operating d/yr, eliminating black liquor from the ESP control system has the potential to reduce average gaseous organic HAP emissions by about 22 Mg/yr (24 ton/yr). This emission reduction represents the difference in emissions between NDCE recovery furnaces with black liquor in the ESP control system (i.e., wet-bottom ESP's or dry-bottom ESP's with wet PM return systems) and NDCE recovery furnaces with dry-bottom ESP's and dry PM return systems. Methanol emission reductions account for most of the estimated HAP emission reduction.

3.2.2 Conversion from a DCE Recovery Furnace System to an NDCE Recovery Furnace

The conversion from a DCE recovery furnace system to an NDCE recovery furnace (often referred to as a "low-odor conversion")

Figure 3-16. Methanol emissions for NDCE recovery furnaces.⁵²

offers significant emission reduction and operational benefits. This conversion is an effective measure for reducing HAP emissions from a DCE recovery furnace system because it eliminates two sources of HAP emissions, the DCE and BLO unit. Conversion from a DCE recovery furnace system to an NDCE recovery furnace is a common modification; an estimated 24 percent of existing NDCE recovery furnaces were originally installed as DCE recovery furnaces.^{1,61,62} These conversions have been performed for several reasons, including compliance with Federal and State TRS emission standards and increased energy efficiency. Other factors influencing the decision to convert a DCE recovery furnace system to an NDCE design include the age of the existing DCE recovery furnace, the condition of the system, and whether additional capacity is needed at the mill. The following sections describe the major modifications involved in converting a DCE recovery furnace system to an NDCE recovery furnace, including operational benefits, and present the potential HAP emission reductions.

3.2.2.1 Description. The major modifications involved in converting a DCE recovery furnace system to an NDCE recovery furnace are (1) replacing the DCE with a concentrator and associated equipment, (2) extending or replacing the economizer, (3) rebuilding or replacing the ESP, and (4) removing the BLO unit. Removal of the DCE is the driving force behind the latter three major modifications.

The DCE is replaced with a concentrator, which can achieve the desired black liquor solids content without direct contact between recovery furnace exhaust gases and black liquor. Eliminating contact between the hot exhaust gases and black liquor is desirable because the emissions that result from stripping are also eliminated. Operational benefits of replacing the DCE with a low-pressure, steam-driven concentrator include the higher solids content achievable, improved energy utilization, and reduced energy costs.⁶³ The concentrator, which may be one of several types, including falling film and forced circulation, is installed as part of the evaporator plant. With

current concentrator technologies, the final solids content of the black liquor before firing is generally limited to 75 percent; however, concentrator technologies that can achieve or exceed a solids content of 80 percent are currently in operation.⁶⁴ For existing DCE recovery furnace systems, the average solids content of the fired black liquor is 65 percent; for existing NDCE recovery furnaces, the average solids content of the fired black liquor is 68 percent.¹ Increasing the solids content of the fired black liquor is advantageous because it reduces the amount of energy required to evaporate residual moisture from the black liquor solids.

The economizer is modified to recover additional heat from the flue gas that has become available with removal of the DCE. The additional heat recovered in the economizer can be used to produce more low-cost, high-pressure steam.⁶³ To produce additional steam, the recovery furnace economizer is either expanded with the addition of modules or replaced (i.e., with a long-flow economizer). The economizer is the last section of the recovery furnace that absorbs heat from the flue gas for steam production. The economizer optimizes the thermal efficiency of the recovery furnace by lowering the exit temperature of the exhaust gas as much as possible while minimizing cold-end corrosion. Typical design exit temperatures for an NDCE recovery furnace range from 176° to 190°C (350° to 375°F). For a DCE recovery furnace system, an exit flue gas temperature of 370°C to 430°C (700°F to 800°F) is required to operate the DCE.⁶⁵ The thermal efficiency of the recovery furnace increases by 1 percent for every 22°C (40°F) drop in exit gas temperature.⁶⁴ Direct contact evaporator recovery furnaces typically operate at thermal efficiencies of 53 to 58 percent, whereas NDCE recovery furnaces typically operate at thermal efficiencies of 63 to 68 percent.⁶⁵ Auxiliary equipment that is required when expanding an economizer includes additional soot blowers, hoppers, and conveyors, which collect and transport the additional ash from the economizer.

The ESP is modified to handle the greater PM loading that results from the removal of the DCE. The DCE acts as a PM

control device, collecting 20 to 40 percent of PM emissions from the recovery furnace.⁷ Thus, removal of the DCE, without upgrading the ESP, would likely result in increased PM emissions from the recovery furnace stack. Because of the increased PM emissions and a possible change in gas flow rate, the ESP may need to be either upgraded or replaced. As discussed in Section 3.1.1.1, the characteristics of the gas stream for NDCE recovery furnaces contribute to reduced ESP corrosion rates in comparison to DCE recovery furnaces.

With the removal of the DCE, the BLO unit is no longer needed; therefore, the emissions associated with the air-sparging BLO units are eliminated. The operational benefits associated with removing an air-sparging BLO unit are the elimination of the high costs associated with operating this unit and the increased heating value of the black liquor.

3.2.2.2 HAP Emission Reduction Potential. As shown in Table 3-7, the conversion from a DCE recovery furnace system to an NDCE recovery furnace results in substantial reductions for all of the gaseous organic HAP compounds. Based on the available emission test data, the conversion from a DCE recovery furnace system to an NDCE recovery furnace reduces total gaseous organic HAP emissions by approximately 93 percent.⁵⁵ In addition to a lower HAP emission potential, NDCE recovery furnaces also emit lower TRS emissions.¹⁵

Figure 3-17 presents methanol emission data for DCE recovery furnace systems and for NDCE recovery furnaces equipped with dry-bottom ESP's and dry PM return systems.⁵⁴ For the DCE recovery furnace systems presented in Figure 3-17, only the methanol emission data from mills that measured emissions from both the DCE recovery furnace and the BLO unit were included. There are three cases in Figure 3-17 where more than one DCE recovery furnace is present at a mill (MO1 and MO4, MP1/2 and MP3, and PB3 and PB4). In those cases, a portion of the total BLO methanol emissions was attributed to each recovery furnace system based on the BLS firing rates measured for the DCE recovery furnaces during the emission tests. (Note: Emissions for MP1/2 are

TABLE 3-7. HAP EMISSIONS FOR DCE RECOVERY FURNACE SYSTEMS AND NDCE RECOVERY FURNACES⁵⁵

Hazardous air pollutant	DCE recovery furnace system		NDCE recovery furnace		Percent reduction
	Emission factor, mass/mass BLS ^{a,b}	Mass rate, kg/yr (lb/yr) ^c	Emission factor, mass/mass BLS ^{b,d}	Mass rate, kg/yr (lb/yr) ^c	
Total organic HAP's ^e	5.15×10^{-4}	123,000 (271,000)	3.67×10^{-5}	8,760 (19,300)	93
Acetaldehyde	4.47×10^{-5}	10,700 (23,500)	1.52×10^{-5}	3,630 (8,000)	66
Benzene	1.57×10^{-5}	3,750 (8,270)	1.73×10^{-6}	413 (911)	89
Formaldehyde	3.11×10^{-6}	742 (1,640)	1.93×10^{-6}	461 (1,020)	38
Methanol	3.43×10^{-4}	81,900 (181,000)	4.93×10^{-6}	1,180 (2,600)	99
Methyl ethyl ketone	1.28×10^{-5}	3,050 (6,720)	1.80×10^{-6}	430 (948)	86
Methyl isobutyl ketone	1.39×10^{-5}	3,310 (7,300)	2.27×10^{-6}	542 (1,200)	84
Phenol	4.14×10^{-5}	9,890 (21,800)	2.05×10^{-6}	490 (1,080)	95
Toluene	1.12×10^{-5}	2,670 (5,880)	2.03×10^{-6}	485 (1,070)	82
Xylenes	2.90×10^{-5}	6,920 (15,300)	4.76×10^{-6}	1,140 (2,510)	84
HCl	1.20×10^{-4}	28,700 (63,200)	1.20×10^{-6}	28,700 (63,200)	—

^aEmission factors for gaseous organic HAP's are based on the sum of the average emission factors for DCE recovery furnaces and BLO units.

^bEmission factor for HCl is based on the average emission factor for all recovery furnaces since no overall change in HCl emissions is expected from converting a DCE recovery furnace system to an NDCE recovery furnace.

^cMass rates are based on a furnace size of 700,000 kg BLS/d (1.5 million lb BLS/d) and 351 operating d/yr.

^dEmission factors for gaseous organic HAP's are based on the average emission factors for NDCE recovery furnaces equipped with dry-bottom ESP's and dry PM return systems.

^eTotal organic HAP's include all gaseous HAP's in this table except HCl. Numbers may not add exactly due to rounding.

Figure 3-17. Methanol emissions for DCE recovery furnace systems and NDCE recovery furnaces.⁵²

actually the combined emissions for DCE recovery furnaces MP1 and MP2, which have a combined stack.)

As shown in Figures 3-18 and 3-19, DCE recovery furnace systems have more gaseous organic HAP emission points than NDCE recovery furnaces (HAP emission points are shaded in the figures). In the DCE system, gaseous organic HAP's such as methanol can be stripped off in the DCE and wet-bottom ESP by contact between the hot flue gases and the black liquor. The BLO vents are also an emission source for methanol and other gaseous organic HAP's because gaseous organic HAP's can be stripped from the black liquor and vented as the oxidizing air is forced up through the black liquor. As described in Section 3.3.1., the wet-bottom ESP (commonly associated with DCE recovery furnaces) can be converted to a dry-bottom ESP with a dry PM return system, thereby eliminating the ESP system as a source of methanol emissions.

For a DCE recovery furnace system with a furnace size of 700,000 kg BLS per day (1.5 million lb BLS per day) and 351 operating d/yr, converting the furnace system to an NDCE design has the potential to reduce average gaseous organic HAP emissions by about 114 Mg/yr (126 ton/yr). This emission reduction represents the difference in emissions between DCE recovery furnace systems (including the BLO unit) and NDCE recovery furnaces (with dry-bottom ESP's and dry PM return systems). Methanol emissions reductions account for most of the estimated gaseous organic HAP emission reduction.

Figure 3-18. Emission sources for a DCE recovery furnace system.

Figure 3-19. Emission sources for an NDCE recovery furnace.

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