
Control of Stationary Sources

I. INTRODUCTION

Control of stationary sources of air pollution requires the application of the control concepts mentioned in Chapter 28, and usually the adaptation of the control devices mentioned in the two previous chapters. In some cases, more than one system or device must be used to achieve satisfactory control. The three general methods of control are (1) process change to a less polluting process or to a lowered emission from the existing process through modification of the operation, (2) fuel change to a fuel which will give the desired level of emissions, and (3) installation of control equipment. It is more efficient to engineer air pollution control into the source when it is first considered than to leave it until the process is operational and found to be in violation of emission standards. Most new large stationary sources of air pollution in the United States are regulated under the Clean Air Act Amendments of 1990 [1] and are legally required to comply with the Amendments.

Existing stationary sources may require modification of existing systems or installation of newer, more efficient control devices to meet more restrictive emission standards. Such changes are often required by control agencies when it can be shown that a new control technology is superior to older systems or devices being used. This is usually referred to as application of the

Best Available Control Technology (BACT). The BACT standards have been incrementally replaced with risk-based standards, meaning that sources may need to apply more stringent technologies as well as important measures to reduce emissions further (e.g. pollution prevention).

Installation of control systems may have a positive economic benefit, which will offset a portion of their cost [2]. Such benefits include (1) tax deduction provisions, (2) recovery of materials previously emitted, (3) depreciation schedules favoring the owner of the source, and (4) banking or sale of the emission offset credits if the source is in a nonattainment area.

II. ENERGY, POWER, AND INCINERATION

Thermal energy, power generation, and incineration have several factors in common. All rely on combustion, which causes the release of air pollutants; all exhaust their emissions at elevated temperatures; and all produce large quantities of ash when they consume solid or residual fuels. The ratio of the energy used to control pollution to the gross energy produced can be a deciding factor in the selection of the control system. These processes have important differences, which influence the selection of specific systems and devices for individual facilities.

A. Energy-Producing Industries

Stationary energy-producing systems are of two general types, residential and commercial space heating and industrial steam generation. The smaller systems (residential and commercial heating) are usually regulated only with respect to their smoke emission, even though they may produce appreciable amounts of other air pollutants [3]. The large industrial systems which generate steam for process use and space heating (where superheated or high-temperature saturated steam is used for a process, e.g. cogeneration, exhausted from the process at a lower energy level, and then introduced into a space heating system, where it gives up a large amount of latent energy, condensing to hot water) are required to comply with rigid standards in most countries.

Control of air pollution from energy-producing industries is a function of the fuel used and the other variables of the combustion process. The system must be thoroughly analyzed before a control system is chosen. The important variables are listed in Table 32.1. For particulate matter control, the variables of process control such as improved combustion, fuel cleaning, fuel switching, and load reduction through conservation should be considered before choosing an add-on control system. If the particulate matter emission is still found to be in excess of standards, then control devices must be used. These include inertial devices (such as multiple cyclones), baghouses, wet and dry scrubbers, electrostatic precipitators (ESPs), and some of the previously discussed novel

devices. Series combinations of control devices may be necessary to achieve the required level of particulate matter emission. A commonly used system is a multiple cyclone followed by a fine-particle control system, such as a baghouse, scrubber, or ESP.

Opacity reduction is the control of fine-particulate matter (less than $1\ \mu\text{m}$). It can be accomplished through the application of the systems and devices discussed for control of particulate matter and by use of combustion control systems to reduce smoke and aerosol emission. In addition, operational practices such as continuous soot blowing and computerized fuel and air systems should be considered.

Sulfur dioxide reduction to achieve required emission levels may be accomplished by switching to lower-sulfur fuels. Use of low-sulfur coal or oil, or even biomass such as wood residue as a fuel, may be less expensive than installing an SO_2 control system after the process. This is particularly true in the wood products industry, where wood residue is often available at a relatively low cost.

If an SO_2 control device is necessary, the first decision is whether to use a wet or dry system. Many times this decision is based on the local situation regarding the disposal of the collected residue (sludge or dry material). Wet scrubbing systems, using chemical additions to the scrubbing liquid, are widely used. Various commercial systems have used lime or limestone, magnesium oxide, or sodium hydroxide slurries to remove the SO_2 . Dry removal of SO_2 can be accomplished by adding the same chemicals used in wet scrubbers, but adding them in a spray drier and then removing the spent sulfates with a baghouse or ESP. This results in the collection of a dry material which may be either disposed of by landfilling or used as a raw material for other processes. The electric power generating industry has had many years of experience with SO_2 control systems [4]. These methods are discussed in more detail in the next section.

Control of oxides of nitrogen can be accomplished by catalysts or absorbants, but most control systems have concentrated on changing the combustion process to reduce the formation of NO_x . Improved burners, change in burner location, staged combustion, and low-temperature combustion utilizing fluidized-bed systems are all currently in use. These combustion improvement systems do not generate waste products, so no disposal problems exist.

B. Power Generation

In general, plants-producing electric power are much larger than those producing steam for space heating or process use. Therefore, the mass of emissions is much greater and the physical size of the control equipment larger.

The extensive control of particulate matter, opacity, SO_2 , and NO_x required on new power plants is very expensive. The high-projected cost of

environmental control for a new coal-fired electric generating plant has made utility companies reluctant to risk the billions of dollars necessary to use coal as a major fuel, particularly when the standards are being constantly redefined and changed [5]. It does appear that the 1990 Amendments will require more complex emission controls as an integrated part of the plant rather than the previous approach of adding control devices independently. Figure 34.1 illustrates the complexity of the current technology for the various alternative systems.

Figure 34.1(a) presents the integrated environmental control potential for maximum control of particulate matter and SO_2 . Cooling tower water blow-down and treatment by-products may be used to satisfy scrubber makeup requirements. Fly ash and scrubber sludge will be produced separately. If the catalytic NO_x process is required, the integration issues will be increased significantly.

Figure 34.1(b) is similar to Fig. 34.1(a) except that an ESP is used for particulate control. This represents the most common approach for compliance when configured without a catalytic NO_x unit.

Figure 34.1(c) is distinctly different from the first two in the type of SO_2 control processes used and the sequence of the particulate matter and SO_2 controls. It is a promising approach for up to 90% SO_2 control of western United States coal, and there is a single waste product. Other features include the collection of particulate matter at temperatures below 90°C and the possibility for spray dryer cooling tower water integration. This system may or may not include a catalytic NO_x unit.

Figure 34.1(d) represents the simplest, least expensive, and lowest water consumer of all the alternatives. There is a single solid waste product. The key element is the integrated SO_2 /particulate control process. Using sodium-based sorbants, compliance may be achievable for western United States coals.

Figure 34.1(e) includes a hot ESP for fly ash collection prior to a catalytic NO_x unit. Having a hot ESP dictates the use of a conventional wet scrubber and perhaps the need for a second particulate matter control device at the end of the system. Fly ash and scrubber sludge would be separate by-products, but sludge could be contaminated with NH_4 from the catalytic NO_x process.

Figure 34.2 illustrates a wet SO_2 desulfurization system using a spray tower absorber. Figure 34.3 illustrates a rotary atomizer injecting an alkaline slurry into a spray dryer for SO_2 control.

Selection and installation of an integrated air pollution control system do not end the concern of the utility industry. Maintenance and operational problems of the system are considered by many engineers to be the weak link in the chain of power generation equipment [6]. The reliability of the flue gas desulfurization system (FGDS) is defined as the time the system operates properly divided by the time it should have operated. For large US power plants, this has been determined by the US Environmental Protection Agency to be 83.3% in 1980 and 82.0% in 1981. These figures are cause for

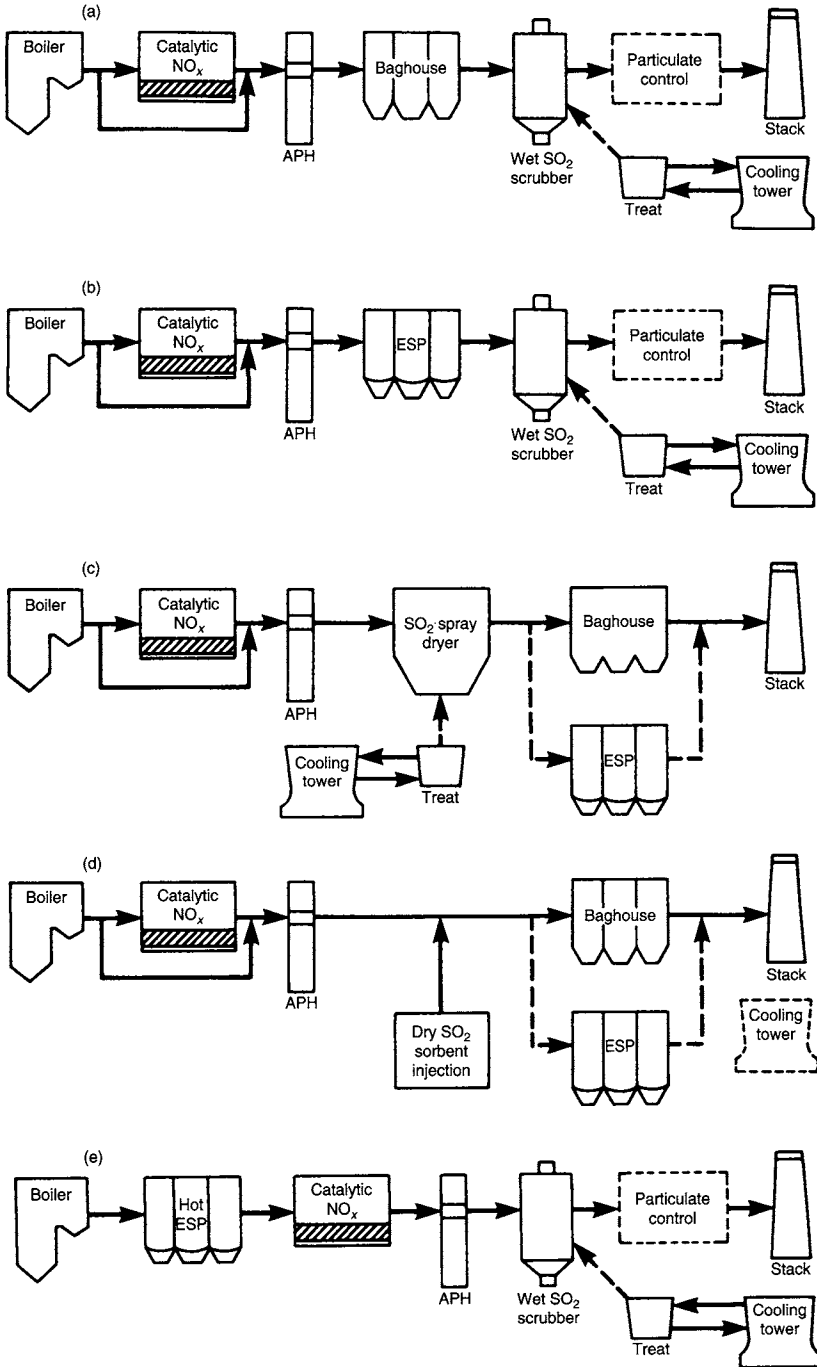


Fig. 34.1. Integrated environmental control for electric generating plants [5].

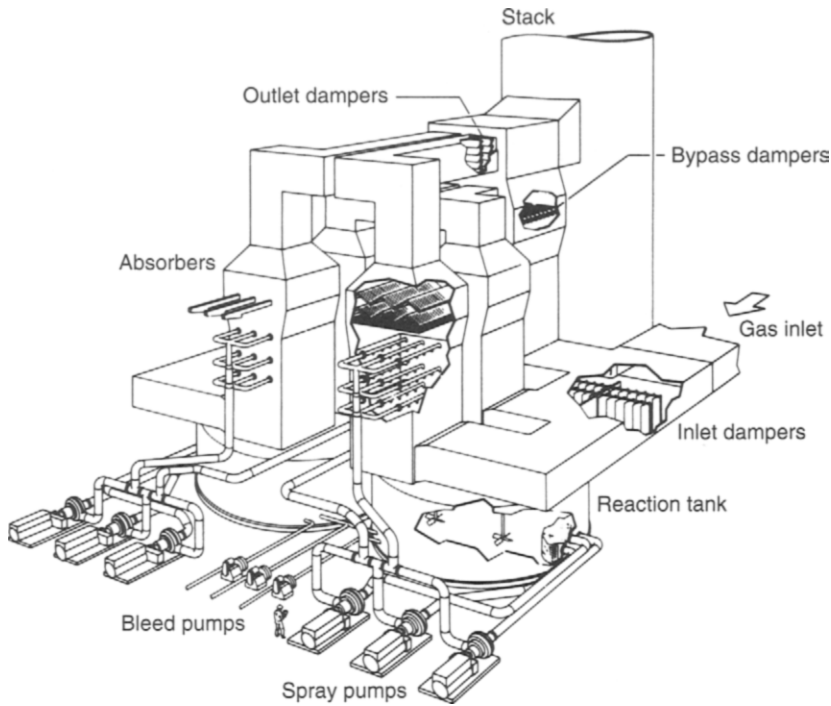


Fig. 34.2. Cutaway drawing of a flue gas desulfurization spray tower absorber. Source: CE Power Systems, Combustion Engineering, Inc.

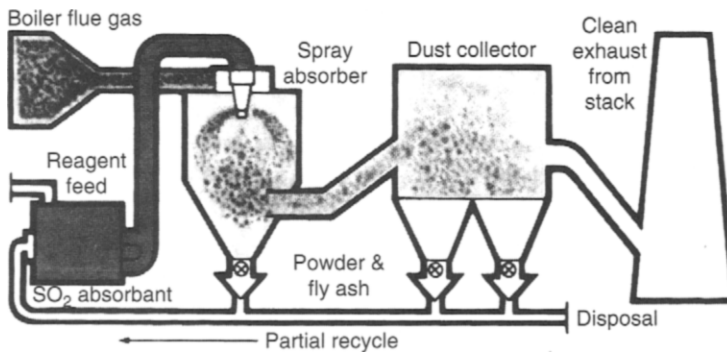


Fig. 34.3. Alkaline slurry SO_2 spray dryer. Source: Niro Atomizer, Inc.

concern even though the consequences to the utility may not have been extreme because the FGDS usually could be bypassed. The primary factors cited for low FGDS reliability are (1) plugging, scaling, and corrosion of scrubber internals, mist eliminators, and reheaters; (2) need for open-loop operation and blowdown of scrubber liquor to reduce the corrosive substance concentration and dissolved solids content; (3) corrosion and failure

of stack liners; and (4) plugging and failure of piping, pumps, and valves. Probably more critical are failures of dampers, ducts, and baffles, because this may require plant shutdown to perform maintenance.

Other methods, which should be mentioned because they show potential benefits for pollution reduction from utility stacks include (1) coal cleaning and treatment, (2) atmospheric pressure and pressurized fluidized-bed combustors, (3) conversion of solid fuels to liquid or gaseous fuels, and (4) combustion modification through staged combustors or other systems.

Tall stacks are no longer considered to be an acceptable alternative for controlling emissions from electric power generating plants (see further discussion in Chapter 26, Section V).

C. Incineration

Thermal removal processes are discussed in detail in Chapter 33. Incineration is similar to combustion-generated energy and power processes in that fuel combines with oxygen. The incineration process, however, is designed as a waste disposal process, and if any energy is recovered, it is considered as a secondary system. Ideally, incineration will reduce combustors, [3] conversion of solid fuels to liquid or gaseous fuels, and [4] combustion modification through staged combustors or other systems.

An incinerator will usually have a fuel of varying chemical composition and physical properties, as well as varying moisture content and heating value. In addition the fuel fired in one locality may be vastly different from that fired by an incinerator of similar size and design in another locality. Refuse production in the United States has been estimated to average 2.5 g per person per day in 1970, increasing to 10 kg per person per day by the year 2000.

The air pollutants from incinerators consist of particulate matter (fly ash, carbon, metals and metal oxides, and visible smoke), combustible gases such as CO, organics, polynuclear organic material (POM), and noncombustible gases such as oxides of nitrogen, oxides of sulfur, and hydrogen chloride. The oxides of nitrogen are formed by two mechanisms: thermal NO_x , in which atmospheric nitrogen and oxygen combine at high furnace temperatures, and fuel NO_x , when nitrogen-bearing compounds are incinerated. Hydrogen chloride (HCl) emissions are causing concern because of the increased amounts of halogenated polymers, notably polyvinyl chloride (PVC), in the refuse; 1 kg of pure PVC yields about 0.6 kg of HCl.

POM emissions appear to be a function of the degree of combustion control, decreasing with increasing incinerator size (larger incinerators are more thoroughly instrumented and controlled). Table 34.1 shows the measured emission rates for POM and CO from various-sized incinerators.

Air pollution control systems using wet scrubbers will remove some water-soluble gases, but the removal of particulate matter is the primary concern for a control system. The air pollution control system, therefore, is usually a

TABLE 34.1

Generation and Emission Rates for POM and Carbon Monoxide (CO) from Incinerators

Incinerator type, size, and control	POM (g metric ton ⁻¹)	CO (g kg ⁻¹)
Municipal, 227 metric tons per day, before settling chamber	0.032	0.35
Municipal, 45 metric tons per day, before scrubber	0.258	2.00
Municipal, 45 metric tons per day, after scrubber	0.014	1.00
Commercial multiple chamber, 3 metric tons per day, no control system	1.726	12.50

Source: Brunner [7].

single device such as a wet scrubber, small-diameter multiple cyclones, fabric filters, or ESPs. The multicyclones are the least expensive system and the ESPs the most expensive.

Some novel methods of incineration offer the possibility of reduced emissions. These include "slagging" (operating at such a high temperature that incombustible materials are melted and removed as a fluid slag); fluidized beds (which are useful only on homogeneous or well-classified refuse); suspension burning in cylindrical combustion chambers, which may or may not result in slagging; and pyrolysis, which is destructive distillation in the absence of oxygen.

The emission control requirements set for municipal incinerators by the US Clean Air Act Amendments of 1990 [1] are extensive and complex. Many of the final standards have not been established as of the date of publication of this book. A thorough study of the regulations is necessary for any person dealing with incinerator technology and control.

III. CHEMICAL AND METALLURGICAL INDUSTRIES

The chemical and metallurgical industries of the world are so varied and extensive that it is impossible to cover all of the processes, emissions, and controls in a single chapter.

A. Chemical Industries

The term *chemical industry* applies to a group of industries which range from small, single owner-employee operations to huge complexes employing thousands of people. The number of environmental regulations that the chemical industry must comply with is so extensive that specialized consulting firms have been formed to aid the industry in handling them [8].

1. Inorganic Chemical Processes

Production of major inorganic chemicals in the United State exceeds 200 million metric tons per year produced in over 1300 plants [9]. These inorganic chemicals may be categorized as follows:

- (a) *Acids*: The major acids produced are hydrochloric, hydrofluoric, nitric, phosphoric, and sulfuric. The emissions and usual control methods for the various acid and manufacturing processes are shown in Table 34.2.
- (b) *Bases*: Major bases and caustics produced by the chemical industry are calcium oxide (lime), sodium carbonate (soda ash), and sodium hydroxide (caustic soda). The emissions and usual control methods for the various bases and their manufacturing processes are shown in Table 34.3.
- (c) *Fertilizer*: Fertilizer production is dependent on the production of phosphates and nitrates. Phosphate rock preparation generates some dry particulate matter during drying, grinding, and transferring of the rock. These emissions are controlled by wet scrubbers and baghouses. The atmospheric emissions and control methods for the production processes are shown in Table 34.4.
- (d) *Ammonium Nitrate Fertilizer*: It is produced by the neutralization of nitric acid with ammonia. The primary emission is the dust or fume of ammonium nitrate from the prill tower. The material is of submicron size and, therefore, highly visible. Control is usually performed by a wet scrubber followed by a mist eliminator.

TABLE 34.2

Air Pollution Emissions and Controls: Inorganic Acid Manufacture

Acid	Manufacturing process	Air pollutant emissions	Control methods in use
Hydrochloric	By-product of organic chlorination, salt process, and synthetic HCl	HCl	Absorption
Hydrofluoric	Fluorspar-sulfuric acid	SiF ₄ , HF	Scrubber (some with caustic)
Nitric	Pressure process and direct strong acid	NO, NO ₂ , N ₂ O ₄	Catalytic reduction, adsorption, absorption
Phosphoric	Elemental phosphorus	Particulate matter, fluorides	Baghouse
	Thermal process	H ₃ PO ₄ , H ₂ S	Mist eliminators, alkaline scrubbers
	Wet process	SiF ₄ , HF	Scrubber
Sulfuric	Superphosphoric	Fluorides	Scrubber
	Contact	SO ₂ , acid mist	Scrubbers with mist eliminators, ESPs

TABLE 34.3

Air Pollution Emissions and Controls: Inorganic Base Manufacture

Base	Manufacturing process	Air pollutant emissions	Control methods in use
Calcium oxide (lime)	Rotary kilns, vertical and shaft kilns, fluidized-bed furnaces	Particulate matter	Cyclones plus secondary collectors (baghouse, ESP, wet scrubbers, granular bed filters, wet cyclones)
Sodium carbonate (soda ash)	Solvay (ammoniasoda)	Particulate matter	Wet scrubbers
Sodium hydroxide, caustic soda	Electrolytic	Chlorine Mercury	Alkaline scrubbers Chemical scrubbing and adsorbers

TABLE 34.4

Air Pollution Emissions and Controls: Phosphate Fertilizer Plants

Process	Air pollutant emissions	Control methods in use
Normal superphosphate	SiF ₄ , HF Particulate matter	Venturi or cyclonic scrubber Wet scrubber of baghouse
Diammonium phosphate	Gaseous F, NH ₃ Particulate matter	Venturi or cyclonic scrubber with 30% phosphoric acid Cyclone followed by scrubber
Triple superphosphate, run of pile	SiF ₄ , HF	Venturi or cyclonic scrubber
Triple superphosphate, granular	SiF ₄ , HF, particulate matter	Venturi or packed scrubber

- (e) *Chlorine*: Most of the chlorine manufactured is produced by two electrolytic methods, the diaphragm cell and the mercury cell processes. Both processes emit chlorine to the atmosphere from various streams and from handling and loading facilities. If the gas streams contain over 10% chlorine, the chlorine is recovered by absorption. If the chlorine concentration is less, the usual practice is to scrub the vent gases with an alkaline solution. Mercury is emitted from the mercury cell process from ventilation systems and by-product streams. Control techniques include (1) condensation, (2) mist elimination, (3) chemical scrubbing, (4) activated carbon adsorption, and (5) molecular sieve absorption. Several mercury cell (chloralkali) plants in Japan have been converted to diaphragm cells to eliminate the poisonous levels of methyl mercury found in fish [9].
- (f) *Bromine*: All of the bromine produced in the United States is extracted from naturally occurring brines by steam extraction. The major air pollution concern is H₂S from the stripper if H₂S is present in the brine. The H₂S can either be oxidized to SO₂ in a flare or sent to a sulfur recovery plant.

2. Organic (Petrochemical) Processes

Most petrochemical processes are essentially enclosed and normally vent only a small amount of fugitive emissions. However, the petrochemical processes that use air-oxidation-type reactions normally vent large, continuous amounts of gaseous emissions to the atmosphere [10]. Six major petrochemical processes employ reactions using air oxidation. Table 34.5 lists the atmospheric emissions from these processes along with applicable control measures.

B. Metallurgical Industries

The metallurgical industry offers some of the most challenging air pollution control problems encountered. The gas volumes are huge, and the gas may be at a high temperature. These large, hot gas volumes may convey large quantities of dust or metal oxide fumes, some of which may be highly toxic. Also, gaseous pollutants such as SO₂ or CO may be very highly concentrated in the carrying stream. The process emissions to the atmosphere may have harmful effects on visibility, vegetation, animals, and inert materials, as well

TABLE 34.5

Air Pollution Emissions and Controls: Petrochemical Processes

Petrochemical process	Air pollutant emissions	Control methods in use
Ethylene oxide (most emissions from purge vents)	Ethane, ethylene, ethylene oxide	Catalytic afterburner
Formaldehyde (most emissions from exit gas stream of scrubber)	Formaldehyde, methanol, carbon monoxide, dimethyl ether	Wet scrubber for formaldehyde and methanol only; afterburner for organic vent gases
Phthalic anhydride (most emissions from off-gas from switch condensers)	Organic acids and anhydrides, sulfur dioxide, carbon monoxide, particulate matter	Venturi scrubber followed by cyclone separator and packed countercurrent scrubber
Acrylonitrile (most emissions from exit gas stream from product absorber)	Carbon monoxide, propylene, propane, hydrogen cyanide, acrylonitrile, acetonitrile NO _x from by-product incinerator	Thermal incinerators (gas-fired afterburners or catalytic afterburners) None
Carbon black (most emissions from exit gas stream from baghouse, some fugitive particulate)	Hydrogen, carbon monoxide, hydrogen sulfide, sulfur dioxide, methane, acetylene	Waste heat boiler or flare (no control for SO ₂)
	Particulate matter (carbon black)	Baghouse
Ethylene dichloride (most emissions from exit gas stream of solvent scrubber)	Carbon monoxide, methane, ethylene, ethane, ethylene dichloride, aromatic solvent	None at present, but could use a waste heat boiler or afterburner, followed by a caustic scrubber for hydrochloric acid generated by combustion

as being detrimental to human health. It is no wonder that the metallurgical industries have spent huge sums to control emissions.

1. Nonferrous Metallurgical Operations

Nonferrous metallurgy is as varied as the ores and finished products. Almost every thermal, chemical, and physical process known to engineers is in use. The general classification scheme that follows gives an understanding of the emissions and control systems: aluminum (primary and secondary), beryllium, copper (primary and secondary), lead (primary and secondary), mercury, zinc, alloys of nonferrous metals (primary and secondary), and other nonferrous metals:

- (a) *Aluminum (primary)*: The emissions from primary aluminum reduction plants may come from the primary control system, which vents the electrolytic cells through control devices, or from the secondary system, which controls the emissions from the buildings housing the cells.

Hydrogen fluoride accounts for about 90% of the gaseous fluoride emitted from the electrolytic cell. Other gaseous emissions are SO_2 , CO_2 , CO , NO_2 , H_2S , COS , CS_2 , SF_6 , and various gaseous fluorocarbons. Particulate fluoride is emitted directly from the process and is also formed from condensation and solidification of the gaseous fluorides.

The fluoride removal efficiency of the control equipment at primary aluminum reduction plants is shown in Table 34.6. The removal efficiency for total fluorides is a matter of great concern.

Emission rates using BACT on the three electrolytic cell types are shown in Table 34.7.

- (b) *Beryllium*: It is extracted from the ore in the form of beryllium hydroxide, which is then converted to the desired product, metal, oxide, or alloy [12]. Some of these products are extremely toxic. Table 34.8 lists

TABLE 34.6

Fluoride Removal Efficiencies: Selected Aluminum Industry Primary and Secondary Control Systems

Control system	Total fluoride removal efficiency (%)
Coated filter baghouse	94
Fluid bed dry scrubber	99
Injected alumina baghouse	98
Wet scrubber + wet ESP	99+
Dry ESP + wet scrubber	95
Floating bed	95
Spray screen (secondary)	62–77
Venturi scrubber	98
Bubbler scrubber + wet ESP	99

Source: Iverson [11].

TABLE 34.7

Emissions for Three Electrolytic Aluminum Reduction Cell Types Using Best Available Control Technology (BACT)

Cell type	Emissions with primary and secondary control	
	Fluorides (g kg ⁻¹ Al)	Particulate (g kg ⁻¹ Al)
Prebaked	0.8	3.0
Vertical stud sodberg	1.4	4.6
Horizontal stud sodberg	1.8	6.2

TABLE 34.8

Air Pollution Emissions and Controls: Beryllium Processing

Process	Air pollutant emissions	Control methods in use
Extraction	Beryllium salts	Baghouses
	Acids	Wet collectors
	Beryllium oxides	Baghouses or high-efficiency particulate air (HEPA) filters
Machining	Beryllium dust, fume, mist	Cyclones and baghouses
	Beryllium dust	Baghouses and HEPA filters
	Beryllium oxide dust	Baghouses and HEPA filters

the emissions from the various beryllium production steps, along with the control measures commonly used.

- (c) *Copper*: Most copper is removed from low-grade sulfide ores using pyrometallurgical processes. The copper is first concentrated, then dewatered, and filtered. The copper smelting process consists of roasters, reverberatory furnaces, and converters. Some copper is further refined electrolytically to eliminate impurities.

Some fugitive particulate emissions occur around copper mines, concentrating, and smelting facilities, but the greatest concern is with emissions from the ore preparation, smelting, and refining processes. Table 34.9 gives the emissions of SO₂ from the smelters.

Tall stacks for SO₂ dispersion have been used in the past but are no longer acceptable as the sole means of SO₂ control. Acid plants have been installed at many smelters to convert the SO₂ to sulfuric acid, even though it may not be desirable from an economic standpoint.

The emission of volatile trace elements from roasting, smelting, and converting processes is undesirable from both air pollution and economic standpoint. Gravity collectors, cyclones, and ESPs are used to attain collection efficiencies of up to 99.7% for dust and fumes.

Treatment of slimes for economic recovery of silver, gold, selenium, tellurium, and other trace elements requires fusion and oxidation in

TABLE 34.9

Sulfur Dioxide Emission Rates from Primary Copper Smelters

Process	Emission (g of SO ₂ per kg of copper)
Roasting	325–675
Reverberatory furnaces	150–475
Converters	975–1075
Reverberatory furnaces ^a	275–800
Converters ^a	850–1800

^a Without roasting.

Source: Nelson *et al.* [13].

TABLE 34.10

Sulfur Dioxide Emission Rates from Primary Lead Smelters

Process	Emission (g of SO ₂ per kg of lead)
Sintering	575–1075
Blast furnace	2.5–5
Dross reverberatory furnace	2.5–5

Source: Nelson *et al.* [13].

a furnace. The furnace gases are exhausted through a wet scrubber followed by an ESP to recover the metals.

- (d) *Lead smelting and lead storage battery manufacture:* Lead ores are crushed, ground, and concentrated in a manner similar to the processing of copper ores. Fugitive emissions from these processes include dusts, fumes, and trace metals. Smelting is usually accomplished in a blast furnace after the concentrated ore is sintered. Sintering removes up to 85% of the sulfur.

Gases from the sintering process contain SO₂, dust, and metal oxide fumes. The blast furnace gases contain similar particulates plus SO₂ and CO. Table 34.10 indicates the expected SO₂ emissions.

- (e) *Mercury:* Mercury is produced commercially by processing mercury sulfide (cinnabar). The mercury sulfide is thermally decomposed in a retort or roaster to produce elemental mercury and sulfur dioxide. The off-gases are cleaned by being passed through cyclonic separators, and the mercury is then condensed. The SO₂ is removed by scrubbers before the exhaust gases are released to the atmosphere. Any mercury vapors that escape are collected in refrigerated units and, usually, recovered with a baghouse or ESP. Other systems use absorption with sodium hypochlorite and sodium chloride or adsorption on activated carbon or proprietary adsorbents. The US Environmental Protection

Agency has placed a limit of 2300 g of mercury emission per 24 h on any mercury smelter or process.

- (f) *Zinc*: It is processed very similarly to copper and lead. The zinc is bound in the ore as ZnS, sphalerite. Zinc is also obtained as an impurity from lead smelting, in which it is recovered from the blast furnace slag.

Dusts, fumes, and SO₂ are evolved during sintering, retorting, and roasting, as shown in Table 34.11.

Particulate emissions from zinc processing are collected in baghouses or ESPs. SO₂ in high concentrations is passed directly to an acid plant for production of sulfuric acid by the contact process. Low-concentration SO₂ streams are scrubbed with an aqueous ammonia solution. The resulting ammonium sulfate is processed to the crystalline form and marketed as fertilizer.

- (g) *Other nonferrous metals and alloys*: Nonferrous metals of lesser significance include arsenic, cadmium, and refractory metals such as zirconium and titanium. Air pollution emissions from the manufacture of these metals do not constitute a major problem, although severe local problems may exist near the facility. Control of emissions is usually accomplished by a single device at the exit of the process. In many cases, the material removed by the control device has some value, either as the primary product or as a by-product. Table 34.12 shows some of the atmospheric emissions and control systems used on these metallurgical processes.

Alloys of nonferrous metals, primarily the brasses (copper and zinc) and the bronzes (copper and tin), can cause an air pollution problem during melting and casting. The type and degree of emissions depend on the furnace and the alloy. Control systems consist of hoods over the furnaces and pouring stations to collect the hot gases, ducts and fans, and baghouses or ESPs.

- (h) *Secondary metals*: These metals are those recovered from scrap. Copper (including brass and bronze), lead, zinc, and aluminum are the

TABLE 34.11

Air Pollution Emissions from Primary Zinc Processing

Process	Emissions to the atmosphere			
	Dust (g dscm ⁻¹)	Percent of particles less than 10 μm	SO ₂ (%)	SO ₂ (gm kg ⁻¹ zinc)
Sintering	10	100	4.5-7.0	—
Horizontal retort	0.1-0.3	100	—	—
Roasting	—	—	—	825-1200

Source: Nelson *et al.* [13].

TABLE 34.12

Air Pollution Emissions from Miscellaneous Nonferrous Metallurgical Processes

Metal	Type of process	Air pollutant emissions	Control methods in use
Arsenic	By-product of copper and lead smelters	Arsenic trioxide	Baghouses or ESPs
Cadmium	By-product of zinc and lead smelters	Cadmium, cadmium oxide	Baghouses
Refractory metals Zirconium Hafnium Titanium Columbium	Kroll process, chlorination, and magnesium reduction	Chlorine, chlorides, SiCl ₄	Wet scrubbers
Tantalum Vanadium Tungsten Molybdenum	Separation process	Ammonia	Conversion to ammonium sulfate fertilizer

principal nonferrous secondary metals. Emissions from the recovery processes are similar to those from the primary metallurgical operations except that little or no SO₂ or fluorides are evolved. Baghouses and ESPs are the commonly used control devices.

2. Ferrous Metallurgical Operations

Iron and steel industries are generally grouped as steel mills, which produce steel sheets or shapes, and foundries, which produce iron or steel castings. Some steel mills use electric arc furnaces with scrap steel as the raw material, but the majority are large, integrated mills with the following facilities [14]:

- (a) *Coke making*: Coke is produced from blended coals by either the non-recovery beehive process or the by-product process. The by-product process produces the majority of the coke. Air pollutants from the coke-making process vary according to the point of release from the process and the time the process has been in operation. Table 34.13 shows the emissions, and their control, from the different stages of the by-product process.

Coke is produced by blending and heating bituminous coals in coke ovens to 1000–1400°C in the absence of oxygen.¹ Light weight oils and tars are distilled from the coal, generating various gases during the heating process. Every half an hour or so, the flows of gas, air, and

¹ The principal source for this section is: National Toxicology Program, 2005, Eleventh Report on Carcinogens, Coke Oven Emissions, Substance Profile; <http://ntp.niehs.nih.gov/ntp/roc/eleventh/profiles/s049coke.pdf>; accessed on May 11, 2005.

TABLE 34.13

Air Pollution Emissions and Controls: By-Product Coke Making

Process	Air pollutant emissions	Control methods in use
Coal and coke handling	Fugitive particulate matter	Enclose transfer points and duct to baghouses; pave and water roadways
Coke oven charging	Hydrocarbons, carbon, coal dust	Aspiration systems to draw pollutants into oven, venturi scrubbers
Coke oven discharging (pushing)	Hydrocarbons, coke dust	Hoods to fans and venturi scrubbers, low-energy scrubbers followed by ESPs (may use water spray at oven outlet)
Coke quenching	Particulate matter	Baffles and water sprays
Leaking oven doors	Hydrocarbons, carbon	Door seals with proper operation and maintenance
By-product processing	Hydrogen sulfide	Conversion to elemental sulfur or sulfuric acid by liquid absorption, wet oxidation to elemental sulfur, combustion to SO ₂

waste gas are reversed to maintain uniform temperature distribution across the wall. In most modern coking systems, nearly half of the total coke oven gas produced from coking is returned to the heating flues for burning after having passed through various cleaning and co-product recovery processes. Coke oven emissions are the benzene-soluble fraction of the particulate matter generated during coke production. They are known to contain human carcinogens. These emissions comprise a highly toxic mixture of gases and aerosols.

Coke oven emissions are actually complex mixtures of gas, liquid, and solid phases, usually including a range of about 40 polycyclic aromatic hydrocarbons (PAHs), as well as other products of incomplete combustion; notably formaldehyde, acrolein, aliphatic aldehydes, ammonia, carbon monoxide, nitrogen oxides, phenol, cadmium, arsenic, and mercury. More than 60 organic compounds have been collected near coke plants. A metric ton of coal yields up to 635 kg of coke, up to 90 kg of coke breeze (large coke particulates), 7–9 kg of ammonium sulfate, 27.5–34 L of coke oven gas tar, 55–135 L of ammonia liquor, and 8–12.5 L of light oil. Up to 35% of the initial coal charge is emitted as gases and vapors. Most of these gases and vapors are collected during by-product coke production. Coke oven gas is comprised of hydrogen, methane, ethane, carbon monoxide, carbon dioxide, ethylene, propylene, butylene, acetylene, hydrogen sulfide, ammonia, oxygen, and nitrogen. Coke oven gas tar includes pyridine, tar acids, naphthalene, creosote oil, and coal-tar pitch. Benzene, xylene, toluene, and solvent naphthas may be extracted from the light oil fraction. Coke production in the US increased

steadily between 1880 and the early 1950s, peaking at 65 million metric tons in 1951. In 1976, the United States was second in the world with 48 million metric tons of coke, i.e. 14.4% of the world production. By 1990, the US produced 24 million metric tons, falling to fourth in the world. A gradual decline in production has continued; production has decreased from 20 million metric tons in 1997 to 15.2 million metric tons in 2002. Demand for blast furnace coke also has declined in recent years because technological improvements have reduced the amount of coke consumed per amount of steel produced by as much as 25%.

- (b) *Sintering*: It consists of mixing moist iron ore fines with a solid fuel, usually coke, and then firing the mixture to eliminate undesirable elements and produce a product of relatively uniform size, physically and chemically stable, for charging the blast furnace. Air pollutants are emitted at different points in the process, as indicated in Table 34.14.
- (c) *Iron making*: It is the term used to describe how iron is produced in large, refractory-lined structures called *blast furnaces*. The iron ore, limestone, and coke are charged, heated, and then reacted to form a reducing gas, which reduces the iron oxide to metallic iron. The iron is tapped from the furnace along with the slag, which contains the impurities. A modern alternative to the blast furnace is continuous casting of iron instead of intermittent tapping. The blast furnace gas is exhausted from the top of the furnace, cooled, and cleaned of dust before it is used to fire the regenerative stoves for heating the blast furnace. The atmospheric emissions from the iron making process are listed in Table 34.15.
- (d) *Steelmaking*: The open-hearth steelmaking process produced 80–90% of the steel in the United States until the 1960s, when the basic oxygen process came into wide use. By 1990 less than 5% of US steel was produced by the open-hearth process. Particulate emissions are highest

TABLE 34.14

Air Pollution Emissions and Controls: Sintering

Process	Air pollutant emissions	Control methods in use
Waste gases (main stack gases)	Particulates, CO, SO ₂ , chlorides, fluorides, ammonia, hydrocarbons, arsenic	Gravity separators to cyclones; then ESPs or wet scrubbers with pH adjustment
Sinter machine discharge	Particulate matter	Multiple cyclones, baghouse, or low-energy wet scrubber
Materials handling	Fugitive particulate matter	Hoods over release points to baghouse or multiple cyclones
Sinter cooler	Particulate matter (trace)	Baghouse (if required)

Source: Steiner [14].

TABLE 34.15

Air Pollution Emissions and Controls: Iron Making

Process	Air pollutant emissions	Control methods in use
Blast furnace exhaust gases	Particulate matter	Multiple cyclone plus wet scrubber or wet ESP, two-stage wet scrubber
Slag handling	H ₂ S, SO ₂ (trace)	None
Casting	Particulate matter	Baghouse

Source: Steiner [14].

TABLE 34.16

Air Pollution Emissions and Controls: Basic Oxygen Furnace

Process	Air pollutant emissions	Control methods in use
Hot metal transfer	Graphite and iron oxide particulate matter	Multiple cyclones plus baghouses
Charging and tapping	Particulate matter	Baghouse or venturi scrubber
Furnace waste gases	Particulate matter (7–30 kg per metric ton of steel)	ESP or venturi scrubber
	Carbon monoxide	Flare

during oxygen lancing with a hot metal charge in the furnace. Particulate matter loadings are reported to be in the range of 6–11 kg per metric ton of steel. Most of the particulate matter is iron or iron oxide. Control of the open-hearth particulate matter emissions is accomplished by ESPs or high-energy scrubbers. Only small quantities of SO₂ are emitted, but if venturi scrubbers are used for particulate matter control, they will also reduce the SO₂ emissions. However, severe corrosion problems have been reported for wet scrubbers on open-hearth furnaces [14].

Basic oxygen furnaces (BOFs) have largely replaced open-hearth furnaces for steelmaking. A water-cooled oxygen lance is used to blow high-purity oxygen into the molten metal bath. This causes violent agitation and rapid oxidation of the carbon, impurities, and some of the iron. The reaction is exothermic, and an entire heat cycle requires only 30–50 min. The atmospheric emissions from the BOF process are listed in Table 34.16.

The electric arc furnace process accounted for about 25% of the 1982 US steelmaking capacity [14]. Most of the raw material used for the process is steel scrap. Pollutants generated by the electric furnace process are primarily particulate matter and CO. The furnaces are hooded, and the gas stream containing the particulate matter is

collected, cooled, and passed to a bag-house for cleaning. Venturi scrubbers and ESPs are used as control devices at some mills. Charging and tapping emissions are also collected by hoods and ducted to the particulate matter control device.

After the steel is tapped from the furnace, it is poured into ingots or continuously cast into slabs or billets. Many metallurgical processes are required between the furnace and the finished product. Reheat furnaces cause no air pollution problems. Scarfing processes create a fine iron oxide fume on the steel surface and also release the same fume, which must be controlled by wet scrubbers or ESPs before it reaches the atmosphere. Pickling may result in the release of acid mists. Scrubbing with special solutions may be required for control. Galvanizing is the process of applying a zinc coating and can result in release of zinc oxide emissions to the atmosphere. Control is accomplished through local collection hoods followed by ESPs, wet scrubbers, or baghouses.

- (e) *Ferrous foundry operations*: It produce castings of iron or steel. Many foundry air pollution problems are similar to those of steel mills but on a smaller scale. Potential emissions from foundry operations, along with the usual control methods, are shown in Table 34.17.
- (f) *Ferroalloy production*: Ferroalloys are used to add various elements to iron or steel for specific purposes. Examples are chromium (in the form of ferrochrome) and manganese (in the form of ferromanganese) added to steel to improve its strength or hardness, or nickel and chromium added to steel to increase its corrosion resistance. In the electrolytic production of nickel, iron is not removed from nickel because nickel will be used for the production of stainless steel. The product is marketed as "ferronickel" rather than nickel. Ferrochrome, ferromanganese, and ferrosilicon are produced in high-temperature furnaces which emit copious quantities of metallic fume and particulate matter. Roasting and concentrating the ore prior to ferroalloy production produce particulate matter and oxide emissions; SO₂ and CO are released during reduction; and casting produces metal oxides and fumes.

TABLE 34.17

Air Pollution Emissions and Controls: Iron and Steel Foundries

Process	Air pollutant emissions	Control methods in use
Cupolas	Particulate matter (5–22 kg ton ⁻¹)	Baghouses, wet scrubbers, and ESPs
	Carbon monoxide SO ₂ (25–250 ppm)	Afterburner If necessary, wet scrubber
Sand conditioning, shakeout, molding	Particulate matter	Medium-energy wet scrubbers, baghouses
Core making	Hydrocarbons	Afterburners (thermal or catalytic)

Source: Steiner [14].

IV. AGRICULTURE AND FOREST PRODUCTS INDUSTRIES

The agricultural and forest products industries are dependent on renewable resources for their existence. They are also acutely aware that air pollution can damage vegetation and, therefore threaten their existence. Both industries have been exempt from many air pollution regulations in the past, but now they are finding these exemptions questioned and in some cases withdrawn [15].

A. Agriculture

The term *agriculture* refers to the operations involved in growing crops or raising animals. Dusts, smoke, gases, and odors are all emissions from various agricultural operations.

1. Agronomy

The preparation of soils for crops, planting, and tilling raises dust as a fugitive emission. Such operations are still exempt from air pollution regulations in most parts of the world. The application of fertilizers, pesticides, and herbicides is also exempt from air pollution regulations, but other regulations may cover the drift of these materials or runoff into surface waters. This is particularly true of the materials that are hazardous or toxic.

2. Open Burning

A major source of particulate matter, carbon monoxide, and hydrocarbons is open burning of agricultural residue. Over 2.5 million metric tons of particulate matter per year are added to the atmosphere over the United States from burning rice, grass straw and stubble, wheat straw and stubble, weeds, prunings, and range bush. Figure 34.4 illustrates an open burn of grass straw and stubble following the harvest of the seed crop.

The major effect of such open burning is the nuisance caused by the smoke, but health effects are noticed by sensitive individuals downwind from the burn. Table 34.18 lists the pollutant emissions from grass field burning [15]. Recently, the international community has been concerned about the release of toxic compounds in addition to the more conventional pollutants in Table 34.18. For example, wood smoke is known to contain polycyclic aromatic hydrocarbons and other toxic organics, such as dioxins. The question is how similar is smoke from open burning to that of wood smoke. So-called biomass burning is currently a major area of interest for many countries, both in terms of local exposures and long-range, transcontinental and transoceanic transport.

If the open burning of agricultural residue is permitted, it should be scheduled to minimize the effect on populated areas. This requires burning when the wind is blowing away from the population centers, not burning

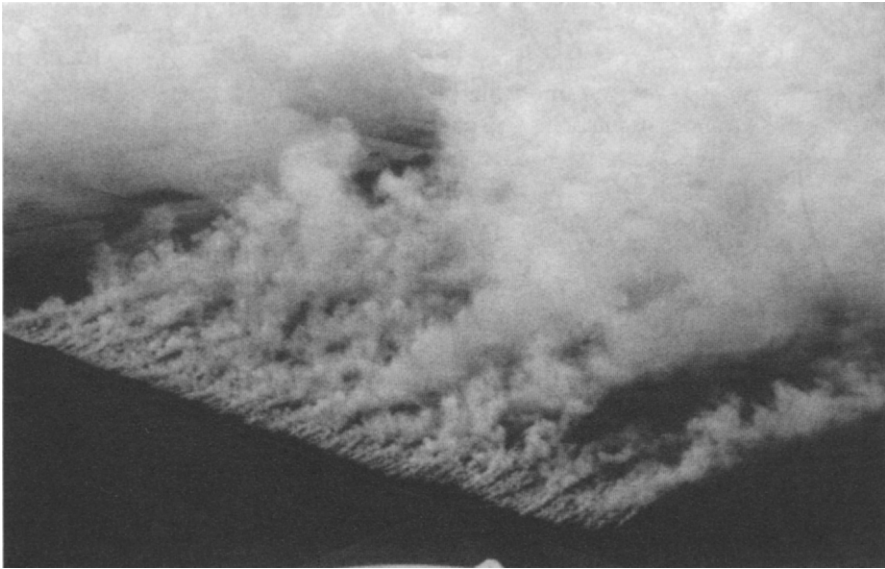


Fig. 34.4. Open burning of a field after a grass seed harvest.

TABLE 34.18

Air Pollution Emission Factors for Agricultural Field Burning	
Pollutant	Emission (kg metric ton ⁻¹)
Particulate matter	8.5
Carbon monoxide	50
Hydrocarbons (as CH ₄)	10
Nitrogen oxides (as NO ₂)	1

Source: Faith [15].

during inversion periods, burning dry residue to establish a strong convection column rather than a smoldering fire, and burning only a certain number of acres at a time, so that the atmosphere does not become overloaded.

3. Orchard Heating

The practice of smudging is still carried out in many areas to protect orchards from frost. Petroleum products are burned in pots, producing both heat and smoke. Since the heat is the desirable product, smokeless heaters with return ducts to reburn the smoke are required by most air pollution control agencies. Some control agencies have passed regulations limiting the smoke to 0.5 or 1.0 g per minute per burner.

Replacement of orchard heaters by wind machines is the most desirable control measure. These large propellers force the warmer air aloft to the ground, where it mixes with the cold air, minimizing frost formation.

4. Alfalfa Dehydration and Pelletizing

Alfalfa dehydration is carried out in a direct-fired rotary dryer. The dried product is transported pneumatically to an air cooler and then to a collecting cyclone. The collected particles are ground or pelletized and then packaged for shipment. The major atmospheric emission from the process is particulate matter, which is controlled by baghouses. Odors may also be a problem, but they disperse rapidly and are no longer a problem at distances of over 1 km.

5. Animal Production

Feeding of domestic animals on a commercial basis results in large quantities of excreta, both liquid and solid. This produces obnoxious odors, which, in turn, produce complaints from citizens of the area. If the animals are concentrated in a feedlot, the odors may become so extreme that odor counteractants are necessary. However, if the feedlots are paved and regularly washed down, the odors may be kept to a satisfactory minimum with much less expense.

Manure is often recycled as a solid organic fertilizer or mixed with water and sprayed as a liquid fertilizer. If the manure is repeatedly used upwind of populated areas, complaints are sure to be filed with the air pollution control agency.

Ammonia (NH₃) is commonly released from animal operations (see Fig. 34.5). For example, in the United Kingdom, emissions from livestock and their

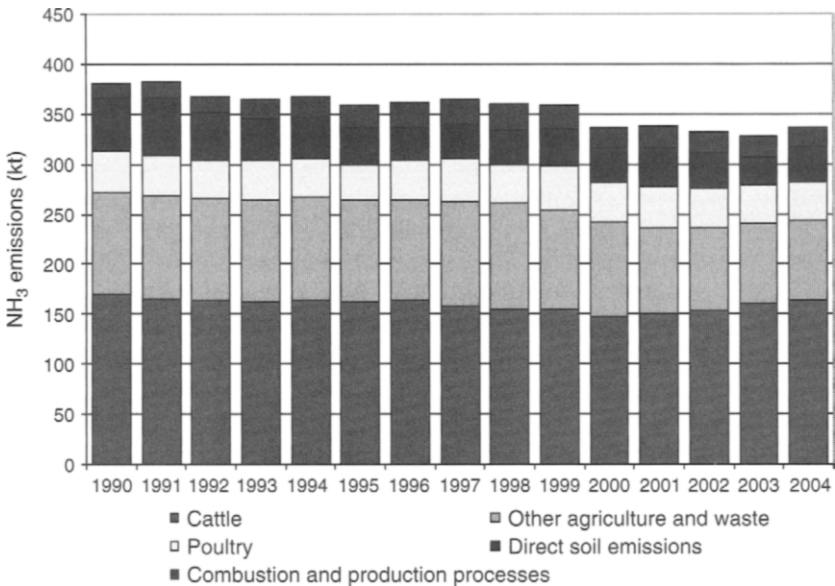


Fig. 34.5. Time series of NH₃ emissions (ktons) in the United Kingdom. Source: United Kingdom National Atmospheric Emissions Inventory and National Environmental Technology Centre, UK Emissions of Air Pollutants 1970–2004. London, UK, 2006.

wastes comprised 79% of the total ammonia emissions. The decomposition of urea in animal wastes and uric acid in poultry wastes accounted for much of these emissions.²

6. Feed and Grain Milling and Handling

All grain milling involves grinding and handling of dried grain. Air streams are used for transport of the raw material and the finished products. The result is atmospheric emissions of grain dust. Originally, the control method used was cyclones; today most systems use baghouses following the cyclones. Caution must be exercised in all phases of baghouse construction, operation, cleaning, etc., as the grain dust is explosive and can cause fires accompanied by loss of property and even of lives. Particulate emissions from uncontrolled grain-processing plants range from 0.1 to 2.0 kg of particulate matter per metric ton of grain [16].

7. Cotton Processing

The processing of cotton, from the field to the cloth, releases both inorganic and organic particulate matter to the atmosphere. Also, adhering pesticide residues may be emitted at the cotton gin exhaust. Table 34.19 lists the emission factors for particulate matter from cotton ginning operations.

8. Meat and Meat Products

The control of odors from holding pens and yards is similar to that discussed in this chapter, Section IV, A, 5. Odors can arise during rendering, cooking, smoking, and processing. Since most of the emissions from the meat products industry are odorous organics, afterburners are used successfully as control devices. Some processors have tried to use wet scrubbers or ESPs, but the emissions are often sticky and can cause severe cleaning problems. Fish processing has similar problems and solutions.

TABLE 34.19

Particulate Matter Emissions from Cotton Ginning	
Process	Emissions (kg bale) ^a
Unloading fan	2.20
Cleaner	0.45
Stick and burr machine	1.35
Miscellaneous	1.35
Total	5.35

^a One bale weighs 277 kg.

Source: Ref. [16].

² United Kingdom National Atmospheric Emissions Inventory and National Environmental Technology Centre, *UK Emissions of Air Pollutants 1970–2004*. London, UK, 2006.

9. *Fruit and Vegetable Processing*

The most severe environmental problem of fruit and vegetable processors is the potential for water pollution if the liquid wastes are not handled properly. Cooking can cause odors, which are usually controlled by using furnaces as afterburners.

One processing problem is presented by the roasting of coffee. This releases smoke, odor, and particulate matter. The particulate matter, primarily dusty and chaff, can be removed with a cyclone. The smoke and odors are usually consumed by passing the roaster exhaust gases through an afterburner. Heat recovery may be desirable if the afterburner is large enough to make it economical.

10. *Miscellaneous Agricultural Industries*

Other industries of interest are (1) the manufacturing of spices and flavorings, which may use activated carbon filters to remove odors from their exhaust stream; (2) the tanning industry, which uses afterburners or activated carbon for odor removal and wet scrubbers for dust removal; and (3) glue and rendering plants, which utilize sodium hypochlorite scrubbers or afterburners to control odorous emissions.

B. Forest Products

The forest products industry encompasses a broad spectrum of operations which range from the raising of trees, through cutting and removing the timber, to complete utilization of the wood residue [17].

1. *Open Burning*

The forest products industry (as well as governmental agencies such as the US Forest Service) practices open, prescribed, burning of logging residue (slash) as a forest management tool and as an economical means of residue disposal [18]. This burning is usually done when meteorological conditions and fuel variables, such as moisture content, can give as clean a burn as possible with a minimum effect on populated areas. On a worldwide basis, it has been estimated that approximately 90 million metric tons of particulate matter from wild and controlled forest and range fires enter the atmosphere each year. Table 34.20 lists the pollutant emissions from forest burning [16].

2. *Wood-Fired Power Boilers*

Wood-fired power boilers are generally found at the mills where wood products are manufactured. They are fired with waste materials from the process, such as "hogged wood," sander dust, sawdust, bark, or process trim. Little information is available on gaseous emissions from wood-fired boilers, but extensive tests of particulate matter emissions are reported [19]. The lignium component of wood is expected in the reaction: wood constituents can

TABLE 34.20

Air Pollution Emission Factors for Forest Burning

Pollutant	Emission (kg metric ton ⁻¹)
Particulate matter	8.5
Carbon monoxide	22
Hydrocarbons (as CH ₄)	2
Nitrogen oxides (as NO ₂)	1

Source: Ref. [16].

TABLE 34.21

Particulate Matter Collection Devices for Wood-Fired Boilers

Pollutant control device	Efficiency (%)
Multiple cyclone	51
Wet scrubber	67
Dry scrubber	85–97 (depending on fuel)
Baghouse	99+

Source: Boubel [19].

be quite variable, such as the cellulose, lignium, and other carbohydrate compounds. As a general rule of combustion, wood can be assumed to have the composition of C_{6.9}H_{10.6}O_{3.5}. However, it also contains many other elements, such as sulfur, phosphorous, and nitrogen, which are oxidized during the firing processes. These emissions range from 0.057 to 1.626 g per dry standard cubic meter, with an average of 0.343 reported for 135 tests. Collection devices for particulate matter from wood-fired boilers are shown in Table 34.21.

3. Driers

Driers are used in the forest products industry to lower the moisture content of the wood product being processed. Drying of dimension lumber gives it dimensional stability. This type of drying is done in steam kilns and is a batch process. No appreciable pollutants are released.

Veneer for the manufacture of plywood is dried on a continuous line in a veneer drier to assure that only dry veneer goes to the layup and gluing process. Glue will not bond if the veneer contains too much moisture. Emissions from the veneer driers are fine particulate and condensed organic material. The condensed organic material is of submicron size and appears as a blue haze coming from the stack. Control is accomplished by means of (1) a wet scrubber or (2) ducting the emissions to a wood-fired boiler, where they are burned. All of these systems must be carefully sized and operated in order to meet a 20% opacity regulation.

Wood particle and fiber driers are used to dry the raw material for particle board and similar products [20]. Just as with the veneer for plywood, the particles must be dried before being mixed with the resins and formed into board. Drying is accomplished in a gas-fired drier, a direct wood-fired drier, or steam coil driers. Many different types of driers are used in the industry. Emissions are fine particles and condensible hydrocarbons, which produce a highly visible plume. Control is accomplished with multiple cyclones or wet scrubbers. Fires in the control equipment and ductwork are quite common and must be expected periodically.

4. Kraft Process Pulp and Paper Plants

The kraft process has become the dominant process for pulp production throughout the world, primarily because of the recovery of the pulping chemicals. A schematic diagram of the kraft pulping process, with the location of atmospheric emission sources, is shown in Fig. 6.11.

Control of air pollutant emissions in modern kraft mills is accomplished by (1) proper operation of the entire mill, (2) high-efficiency ESPs on the recovery furnace (up to 99.7% efficiency for particulate matter, which is recovered and returned to the process), (3) collection of noncondensable gases from several vent points (digesters, blow tanks, washers) and ducting them to the lime kiln, where they are completely burned, and (4) high-energy wet scrubbers on the lime kiln exhaust to remove the particulate matter and sulfurous gases. A more complete analysis of the kraft process, including the emissions and their control, may be found in Ref. [17].

V. OTHER INDUSTRIAL PROCESSES

Many industries operated throughout the world do not fall into the previous categories. Some of these are universal, such as asphalt batching plants, whereas others are regional, such as bagasse-fired boilers. Each has its own emission and control problems and requires knowledgeable analysis and engineering. Some of the more widely used processes are examined in this section.

A. Mineral Products

Conversion of minerals to useful products is a major worldwide industry. Mining or quarrying of minerals can produce fugitive emissions, which may be controlled by paving work and traffic areas, wetting the materials being removed or handled, or using collection and exhaust systems at the site where the particulate matter is being generated. The usual air pollution control device is a multiple cyclone or a baghouse at the system exit. The same control techniques can be applied at other points in the process where the minerals are transported, stored, crushed and ground, concentrated, dried, and mixed [21].

1. Asphaltic Concrete Plants

Two types of asphaltic concrete plants are in common use, batch mix plants and continuous mix plants. Figure 34.6 shows a batch mix asphalt plant. Fugitive emissions occur at the handling areas and at the bin loading facility. The emissions of greatest concern, however, occur at the rotary drier, hot aggregate elevator, and hot aggregate handling systems. Each has the potential for releasing large quantities of uncontrolled particulate matter. Table 34.22 illustrates the large range of emissions from uncontrolled and controlled asphaltic concrete plants.

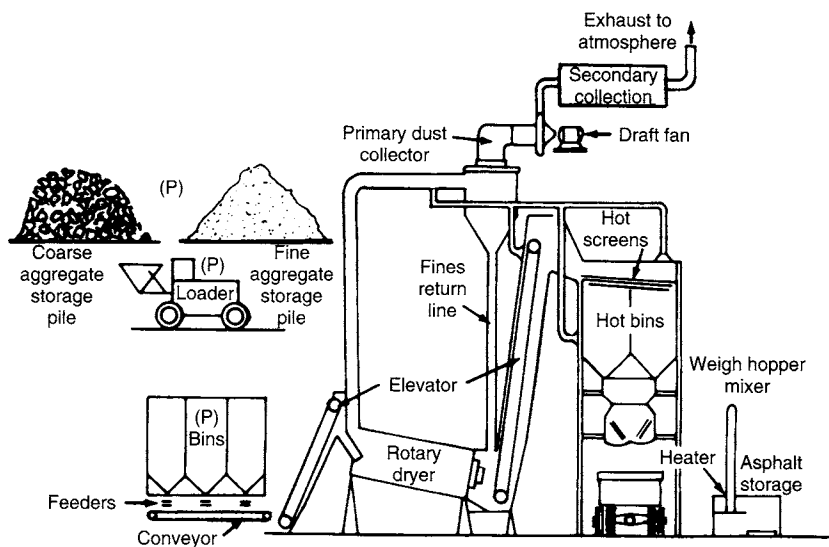


Fig. 34.6. Batch mix asphalt plant; P, denotes fugitive particulate matter emissions. Source: Ref. [16].

TABLE 34.22

Particulate Matter Emission Factors for Asphaltic Concrete Plants

Type of control	Emissions (kg metric ton ⁻¹)
Uncontrolled ^a	22.5
Cyclone precleaner	7.5
High-efficiency cyclone	0.85
Spray tower scrubber	0.20
Multiple centrifugal scrubber	0.15
Baffle spray tower scrubber	0.15
Orifice-type scrubber	0.02
Baghouse ^b	0.05

^a Almost all plants have at least a precleaner following the rotary drier. The fines collected are returned and are an important part of the mix.

^b Emissions from a properly designated, installed, operated, and maintained baghouse collector can be as low as 0.0025–0.010 kg per metric ton. Source: Ref. [16].

2. Cement Plants

Portland cement manufacture accounts for about 98% of the cement production in the United States. The raw materials are crushed, processed, proportioned, ground, and blended before going to the final process, which may be either wet or dry. In the dry process, the moisture content of the raw material is reduced to less than 1% before the blending process occurs. The dry material is pulverized and fed to the rotary kiln. Further drying, decarbonating, and calcining take place as the material passes through the rotary kiln. The material leaves the kiln as clinker, which is cooled, ground, packaged, and shipped.

For the wet process, a slurry is made by adding water during the initial grinding. The homogeneous wet mixture is fed to the kiln as a wet slurry (30–40% water) or as a wet filtrate (20% water). The burning, cooling, grinding, packaging, and shipping are the same as for the dry process.

Particulate matter emissions are the primary concern with cement manufacture. Fugitive emissions and uncontrolled kiln emissions are shown in Table 34.23.

Control of particulate matter emissions from the kilns, dryers, grinders, etc. is by means of standard devices and systems: (1) multiple cyclones (80% efficiency), (2) ESPs (95% + efficiency), (3) multiple cyclones followed by ESPs (97.5% efficiency), and (4) baghouses (99.8% efficiency).

3. Glass Manufacturing Plants

Soda-lime glass accounts for about 90% of the US production. It is produced in large, direct-fired, continuous-melting furnaces in which the blended raw materials are melted at 1480°C to form glass. The emissions from soda-lime

TABLE 34.23

Air Pollution Emission Factors for Portland Cement Manufacturing without Controls

Pollutant	Emissions (kg metric ton ⁻¹)			
	Dry process		Wet process	
	Kilns	Dryers, grinders, etc.	Kilns	Dryers, grinders, etc.
Particulate matter	122.0	48.0	114.0	16.0
Sulfur dioxide ^a	5.1		5.1	—
Mineral source	Neg	—	Neg	—
Gas combustion	2.1 × S ^b	—	2.1 × S ^b	—
Oil combustion	3.4 × S	—	3.4 × S	—
Coal combustion		—		—
Nitrogen oxides	1.3	—	1.3	—

^a If a baghouse is used as control device, reduce SO₂ by 50% because of reactions with an alkaline filter cake.

^b S is the percent of sulfur in the fuel.

Source: Ref. [16].

TABLE 34.24

Air Pollution Emission Factors for Fiber Glass Manufacturing without Controls

Type of process	Emissions (kg/metric ton ⁻¹)				
	Particulate matter	Sulfur oxides as SO ₂	Carbon monoxide	Nitrogen oxides as NO ₂	Fluorides
Textile products					
Glass furnace					
Regenerative	8.2	14.8	0.6	4.6	1.9
Recuperative	13.9	1.4	0.5	14.6	6.3
Forming	0.8	—	—	—	—
Curing ovens	0.6	—	0.8	1.3	—
Wool products					
Glass furnace					
Regenerative	10.8	5.0	0.13	2.5	0.06
Recuperative	14.2	4.8	0.13	0.9	0.06
Electric	0.3	0.02	0.03	0.14	0.01
Forming	28.8	—	—	—	—
Curing ovens ^a	1.8	—	0.9	0.6	—
Cooling ^a	0.7	—	0.1	0.1	—

^a In addition, 0.05 kg per metric ton for phenol and 1.7 kg per metric ton for aldehyde during curing and cooling.

Source: Ref. [16].

glass melting are 1.0 kg of particulate matter per metric ton of glass and $2 \times$ (fluoride percentage) for the fluoride emissions in kilograms per metric ton. For effective control of the emissions, baghouses are used.

Fiberglass is manufactured primarily from borosilicate glass by drawing the molten glass into fibers. Two fiberglass products are produced, textile and glass wool. The emissions from the two processes are shown in Table 34.24 [16]. Control is achieved through proper design and operation of the manufacturing operations rather than by add-on devices.

B. Petroleum Refining and Storage

A modern petroleum refinery is a complex system of chemical and physical operations. The crude oil is first separated by distillation into fractions such as gasoline, kerosene, and fuel oil. Some of the distillate fractions are converted to more valuable products by cracking, polymerization, or reforming. The products are treated to remove undesirable components, such as sulfur, and then blended to meet the final product specifications. A detailed analysis of the entire petroleum production process, including emissions and controls, is obviously well beyond the scope of this text. The reader is referred to Refs. [16, 22, 23]. Reference [16] presents an extensive tabulation of the emission sources for all processes involved in petroleum refining and production, some of which are summarized in Table 34.25.

TABLE 34.25

Sources of Emissions from Oil Refining

Type of emission	Source
Hydrocarbons	Air blowing, barometric condensers, blind changing, blowdown systems, boilers, catalyst regenerators, compressors, cooling towers, decoking operations, flares, heaters, incinerators, loading facilities, processing vessels, pumps, sampling operations, tanks, turnaround operations, vacuum jets, waste effluent handling equipment
Sulfur oxides	Boilers, catalyst regenerators, decoking operations, flares, heaters, incinerators, treaters, acid sludge disposal
Carbon monoxide	Catalyst regenerators, compressor engines, coking operations, incinerators
Nitrogen oxides	Boilers, catalyst regenerators, compressor engines, flares
Particulate matter	Boilers, catalyst regenerators, coking operations, heaters, incinerators
Odors	Air blowing, barometric condensers, drains, process vessels, steam blowing, tanks, treaters, waste effluent handling systems
Aldehydes	Catalyst regenerators, compressor engines
Ammonia	Catalyst regenerators

Source: Elkins [23].

Control of atmospheric emissions from petroleum refining can be accomplished by process change, installation of control equipment, and improved housekeeping and maintenance. In many cases, recovery of the pollutants will result in economic benefits. Table 34.26 lists some of the control measures that can be used at petroleum refineries.

C. Sewage Treatment Plants

The concern with atmospheric emissions from sewage treatment plants involves gases and odors from the plant itself, particulate matter and gaseous emissions from the sludge incinerator if one is used, and all three pollutants (gases, odors, and particulate matter) if sludge disposal is conducted at the site. The gases and odors are combustible, so afterburners or flares are used. Some plants use the sewage gas to fire small stationary boilers or fuel gas–diesel engines for plant energy. Particulate matter from sludge incinerators is usually scrubbed with treated water from the plant, and the effluent is returned to the incoming plant stream. If the odors are too persistent, masking agents are sometimes specified to lessen the objections of the public.

D. Coal Preparation Plants

Coal preparation plants are used to reduce noncombustibles and other undesirable materials in coal before it is burned.

TABLE 34.26

Control Measures for Air Pollutants from Petroleum Refining

Source	Control method
Storage vessels	Vapor recovery systems; floating roof tanks; pressure tanks; vapor balance; painting tanks white
Catalyst regenerators	Cyclones-precipitator-CO boiler; cyclones-water scrubber; multiple cyclones
Accumulator vents	Vapor recovery; vapor incineration
Blowdown systems	Smokeless flares-gas recovery
Pumps and compressors	Mechanical seals; vapor recovery; sealing glands by oil pressure; maintenance
Vacuum jets	Vapor incineration
Equipment valves	Inspection and maintenance
Pressure relief valves	Vapor recovery; vapor incineration; rupture disks; inspection and maintenance
Effluent waste disposal	Enclosing separators; covering sewer boxes and using liquid seals; liquid seals on drains
Bulk loading facilities	Vapor collection with recovery or incineration; submerged or bottom loading
Acid treating	Continuous-type agitators with mechanical mixing; replace with catalytic hydrogenation units; incinerate all vented cases; stop sludge burning
Acid sludge storage and shipping	Caustic scrubbing; incineration, vapor return system
Spent caustic handling	Incineration; scrubbing
Doctor treating	Steam strip spent doctor solution to hydrocarbon recovery before air regeneration; replace treating unit with other, less objectionable units (Merox)
Sour water treating	Use sour water oxidizers and gas incineration; conversion to ammonium sulfate
Mercaptan disposal	Conversion to disulfides; adding to catalytic cracking charge stock; incineration; using material in organic synthesis
Asphalt blowing	Incineration; water scrubbing (nonrecirculating type)
Shutdowns, turnarounds	Depressure and purge to vapor recovery

Source: Buonicore and Davis [22].

E. Gas Turbines

Gas turbines are used as prime movers for pumps, electric generators, and large rotating machinery. Their main economic advantage is driving high-horsepower, consistent loads. Many stationary gas turbines use the same core engine as their jet engine counterpart.

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QUESTIONS

1. Rank the control systems shown in Fig. 34.1 according to their relative capital construction and operation costs.
2. Justify the statement, "Tall stacks are no longer considered as an acceptable alternative for controlling emissions from electric power generating plants."
3. For the New Source Performance Standards (NSPS) for incinerators, only particulate matter emissions are covered. Devise a standard which would also include POM, CO, and NO_x for large municipal incinerators.
4. What advantage is gained by oxidizing H_2S to SO_2 ? (Consider toxicity and odors.)
5. Why are total fluoride emissions from an aluminum smelter of more concern than gaseous or solid fluoride emissions?
6. What systems can be used to detect and prevent grain dust explosions?
7. Would you expect wood-fired boilers to emit more or less CO per metric ton of fuel than coal-fired boilers? More or less NO_x ? More or less SO_2 ?
8. What would be the ultimate disposal of dry material collected by an ESP at a cement plant kiln outlet? What would be the ultimate disposal of wet sludge from a scrubber on a cement plant kiln outlet?
9. Petroleum plants may have a disposal problem with sulfur removed from their products. What are some potential uses for this sulfur?