VOLUME II: CHAPTER 12

HOW TO INCORPORATE THE EFFECTS OF AIR POLLUTION CONTROL DEVICE EFFICIENCIES AND MALFUNCTIONS INTO EMISSION INVENTORY ESTIMATES

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DISCLAIMER

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CONTENTS

SECTION PAGE

CONTENTS (CONTINUED)

SECTION **PAGE**

CONTENTS (CONTINUED)

SECTION **PAGE**

CONTENTS (CONTINUED)

SECTION PAGE

CONTENTS (CONTINUED)

SECTION PAGE

CONTENTS (CONTINUED)

SECTION **PAGE**

CONTENTS (CONTINUED)

SECTION **PAGE**

TABLES AND FIGURES

Figures

TABLES AND FIGURES (CONTINUED)

FIGURES **Page**

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1

INTRODUCTION

There are two approaches used by owners and operators of industry to reduce pollution:

- Preventing pollution from forming by alternating manufacturing or production practices, substitution of raw materials, or improved process control methods; and
- Achieving emissions reductions with control equipment which capture or destroy pollutants which would otherwise be released.

Sometimes, both approaches are employed.

Emission inventory preparers often have to estimate emission reductions or emission control efficiencies of specific types of air pollution control devices (APCDs). Also, they sometimes must estimate the effect on emission levels caused by APCD malfunctions. Depending on the known operating characteristics of the facility and purposes of the inventory, state and local inventory preparers may need to apply an adjustment to the control device efficiency values to correct the underestimation of emissions if the control efficiency used is based on design specifications or is based on controls specified by a regulation. Applying an adjustment has the effect of reducing the assumed control device efficiency and increasing the estimated emissions. This is a reasonable assumption since control equipment may sometimes fail or be off line for maintenance, etc. This adjustment has been incorrectly called Rule Effectiveness (RE) and a default value of 80 percent has been frequently used. Much confusion has existed over the Environmental Protection Agency's (EPA) RE policy and its application. EPA has drafted a paper that clarifies the confusion and addresses the applicability of RE to emission inventories and the draft paper is included in Appendix A. Additionally, the Emission Inventory Improvement Program (EIIP) Point Sources Committee has published a technical paper, titled *Emission Inventories and Proper Use of Rule Effectiveness*, addressing the application of RE to emission inventories. The technical paper is also included in Appendix B and may be accessed through EPA's CHIEF web site at: http://www.epa.gov/ttn/chief. Guidance contained in Chapter 12 allows the inventory preparer to avoid the necessity of using the 80 percent adjustment factor.

This document provides background information and can be used as a primer to gain a basic understanding of different air pollution control devices, how they work, the pollutants they control, and how to adjust emission estimates to account for APCD malfunction.

This document focuses only on the following basic types of APCDs used in industry today:

- Mechanical collectors;
- Scrubbers;
- Fabric filters;
- Electrostatic precipitators;
- Incinerators;
- Condensers;
- Catalytic reactors;
- Absorbers (where pollutants are collected as the molecules pass through the surface of the absorbent to become distributed throughout the phase); and
- Adsorbers (where pollutants are collected by concentration on the surface of a liquid or solid).

Various terms may be used to describe a specific air pollution control device. Appendix C presents a cross-reference for terms used to identify air pollution control devices.

EPA uses “criteria pollutants” as indicators of air quality. These pollutants are:

- Ozone (O_3);
- Nitrogen oxides (NO_x);
- Sulfur dioxide (SO_2);
- Particulate matter with aerodynamic diameter less than or equal to 10 microns (PM_{10});
- Particulate matter with aerodynamic diameter less than or equal to 2.5 microns ($PM_{2.5}$);
- Carbon monoxide (CO); and
- Lead (Pb).

While industrial ozone emissions are not usually regulated, EPA also regulates emissions of volatile organic compounds (VOC) under criteria pollutant programs. VOC are ozone precursors—they react with NO_x in the atmosphere in the presence of sunlight to form ozone.

This document identifies the APCDs used for criteria pollutants and presents ranges of typical control efficiencies. Section 2 describes the criteria pollutants. Sections 3 and 4 of this document discuss the different types of APCDs and the pollutants they are intended to control. Appendix G presents data sources for information presented in Section 5. Appendix D provides details on how the control efficiency data were compiled and presented in Section 3 of this document and contains a summary of additional data acquired but not evaluated for this document. Section 5 presents the information necessary (including example calculations) to assist an inventory preparer in determining the impact of APCD malfunction on emissions from point sources. Example calculations and example scenarios are presented in Appendices E and F.

For detailed descriptions and additional information on APCDs, refer to the references listed in Section 6 of this document. Appendix G presents data sources for information presented in Section 5.

1.1 WHAT IS CONTROL EFFICIENCY?

Control efficiency (CE) is a measure of emission reduction efficiency. It is a percentage value representing the amount of emissions that are controlled by a control device, process change, or reformulation.

1.2 HOW DO I DETERMINE CONTROL EFFICIENCY?

Control efficiency is calculated as:

$$\frac{\text{Uncontrolled Emission Rate} - \text{Controlled Emission Rate}}{\text{Uncontrolled Emission Rate}} * 100 \qquad (12.1\text{-}1)$$

If the emission rates (or concentration) are not known and the control efficiency cannot be calculated, another method for determining efficiency is to refer to Section 3 of this document that presents summary tables (Tables 12.3-1 through 12.3-7) for the control efficiencies of APCDs used to reduce nitrogen oxides, sulfur dioxide, volatile organic compounds, particulate matter, and carbon monoxide. These values are averages and may not be accurate for individual situations. Consult permit applications for APCD design efficiencies of particular equipment if needed. Refer to Section 5 for determining control efficiency during APCD malfunction.

For fabric filters, which are used to reduce PM emissions, if the actual (measured) concentration of PM in the inlet stream to the fabric filter and the expected concentration of PM in the outlet stream are known, Equation 12.1-1 may be used to back calculate the control efficiency. Generally, fabric filters are designed to reduce overall PM emissions to below an expected concentration when the inlet concentrations are within a specified range. For example, the design specifications for a fabric filter may state that the expected outlet emissions are 0.01 grains of PM per dry standard cubic foot of stack gas (gr/dscf) when the inlet emissions are between 5 and 20 gr/dscf. Thus, the outlet emission rate remains relatively “constant” even though the inlet concentration varies and, as the inlet emissions decrease, the overall control efficiency is decreased. Therefore controlled emissions are calculated using the dust loading in the flue gas and the exhaust flow rate. There is no need to estimate the control efficiency. Example 12.1-1 shows how PM emissions are calculated using stack gas outlet concentrations and flow rate.

Example 12.1-1

This example shows how to estimate PM emissions from a fabric filter when exit gas flow rate and dust concentration is known.

$E_{PM} = Q \times C$ where:

Q = exit gas flow rate (dscf/min)
C = PM concentration (gr/dscf)

$$\begin{aligned} E_{PM} &= Q \times C \\ &= 50{,}000\ (\text{dscf/min}) \times 0.01\ (\text{gr/dscf}) \\ &= 500\ (\text{gr/min}) \end{aligned}$$

To convert to (lb/hr):

$$\begin{aligned} E(\text{lb/hr}) &= E\ (\text{gr/min}) \times (1\ \text{lb}/7{,}000\ \text{gr}) \times (60\ \text{min/hr}) \\ &= 500\ (\text{gr/min}) \times (1\ \text{lb}/7{,}000\ \text{gr}) \times (60\ \text{min/hr}) \\ &= 4.29\ (\text{lb/min}) \end{aligned}$$

Note that in this example inlet concentration and control efficiency data are not needed.

1.3 CAN I ASSUME APCDS ARE ALWAYS OPERATED AT THE MAXIMUM LEVEL OF EFFICIENCY?

No. Some facilities do not always operate devices at their maximum level of efficiency. Although APCDs should be designed to accommodate reasonable process variation and some deterioration, some types of control devices vary in efficiency based on process equipment operating rates, fuel quality, and age. Usually an emission limit must be met and the primary goal of the facility is to meet that limit. It may or may not be necessary to operate the control device at its maximum level of efficiency in order to meet that limit. Also, in most cases, operation below maximum efficiency can reduce operating costs.

Moreover, as detailed in Section 1.4, there are many factors that may reduce the level of efficiency of a control device.

1.4 HOW DO I ESTIMATE ACTUAL CONTROL EFFICIENCY?

You can use the control efficiencies presented in Tables 12.3-1 through 12.3-7 and information about the operating conditions of the device to estimate actual control efficiency. These are typical values. Facility operators, engineers, and maintenance personnel are most qualified to provide more specific information. You can also use the references in each table for more information. Permit applications may also provide information.

Questions that should be asked or information that should be obtained, are described below:

- How old is the control device? Some devices are affected by age and their control efficiencies deteriorate over time if not properly maintained. In the case of an ESP, for example, the collection efficiency declines due to corrosion, warpage, and the accumulation of non-removeable dust on surfaces.

- Is the control device properly maintained? Most devices require routine maintenance and some devices may require intensive maintenance. For example, the bags (filters) in a fabric filter should be cleaned when they are blinded by a permanently entrained cake of particulate matter. Bags can also develop rips if not replaced frequently enough. The fields in an electrostatic precipitator must be maintained to operate at a specific voltage. If a device is not properly maintained, the control efficiency will be reduced.

- Is the device operated under conditions necessary for maximum efficiency and are these conditions monitored? A fabric filter may be designed to operate at a specific pressure drop in order to attain maximum efficiency and the pressure should be monitored. A thermal incinerator must operate at a particular temperature and residence time, and these parameters should also be monitored. Wet scrubbers must have the scrubbing liquor available at all times in proper amounts. When a device is not operated properly, the control efficiency will be reduced.

- What is the throughput to the control device relative to its design capacity? If a device is operated above its design capacity, the control efficiency may be reduced. For example, if too much gas is forced through a wet scrubber, channeling of gas can result and the control efficiency is reduced.

Note: The inventory preparer should use the information obtained from facility personnel to determine the adjustment to the control efficiency value provided in Tables 12.3-1 through 12.3-7 to estimate an actual control efficiency.

1.5 WHEN MULTIPLE CONTROL DEVICES ARE USED, ARE THEIR EFFICIENCIES ADDITIVE?

No. In general, when estimating the overall control efficiency for a combination of control devices in series, inventory preparers should not assume the overall efficiency is additive or cumulative. This is because control efficiency for a particular device is often dependent on the inlet concentration. The overall control efficiency of a series of APCDs is typically higher than the efficiencies of the individual control devices, but smaller than the sum of the individual control efficiencies. However, in some cases the control efficiencies of multiple devices in series may be assumed to be additive. In this case, the overall control efficiency of a series of "n" devices is:

$$\text{CE (overall)} = 1 - [\, (1 - \text{CE1}/100) * (1 - \text{CE2}/100) * \ldots\ldots\ldots\ldots *(1 - \text{CEn}/100)\,] \quad (12.1\text{-}2)$$

When the last device in a series of control devices is a fabric filter, you should assume that the control efficiency of the APCDs is equal to the control efficiency of the fabric filter, and the other devices help to reduce the load on the fabric filter. For example, suppose a wood boiler is equipped with a multicyclone designed to operate at a control efficiency of 60 percent and a fabric filter designed to operate at 99 percent, then the overall control efficiency is likely to be around 99 percent, and for all practical purposes, can be assumed to be 99 percent.

2

DESCRIPTION OF CRITERIA POLLUTANTS

2.1 OZONE (O_3)

Ozone, a colorless gas, is the major component of smog. Except for very low levels of emissions from a limited number of processes, ozone is not emitted directly into the air but is formed in the atmosphere in the presence of sunlight through complex chemical reactions between precursor emissions of VOC and NO_x in the presence of sunlight. These reactions are accelerated by sunlight and increased temperatures and, therefore, peak ozone levels typically occur during the warmer times of the year.

2.2 NITROGEN OXIDES (NO_x)

Nitrogen oxides include numerous compounds comprised of nitrogen and oxygen. Nitric oxide (NO) and nitrogen dioxide (NO_2) are the most significant nitrogenous compounds, in terms of quantity released to the atmosphere. Generally, sources of NO_x emissions may be categorized either as stationary or mobile, and as combustion processes or noncombustion processes. Nitric oxide is the primary nitrogen compound formed in high temperature combustion processes when nitrogen present in the fuel and/or combustion air combines with oxygen. On a national basis, total emissions of NO_x from noncombustion stationary sources (such as chemical processes) are small relative to those from stationary combustion sources (such as utility boilers).

2.2.1 HOW ARE NITROGEN OXIDES FORMED IN STATIONARY COMBUSTION SOURCES?

The formation of NO_x from a specific combustion device is determined by the interaction of chemical and physical processes occurring within the device. The three principal types of NO_x formations are:

- **Thermal NO_x**: Formed through high temperature oxidation of the nitrogen found in the high-temperature post-flame region of the combustion system. During combustion, oxygen radicals (O) are formed and attack atmospheric nitrogen molecules to start the reactions that comprise the thermal NO_x formation mechanism:

$$O + N_2 \rightleftarrows NO + N$$

$$N + O_2 \rightleftarrows NO + O$$

$$N + OH \rightleftarrows NO + H$$

Four factors influence thermal NO_x formation:

- Temperature;
- Oxygen concentration;
- Nitrogen concentration; and
- Residence time.

Of these, temperature is the most important. Significant levels of NO_x are usually formed above 2200°F under oxidizing conditions, with exponential increases as the temperature increases. Maximum thermal NO_x production occurs at a slightly lean fuel-to-air ratio due to the excess availability of oxygen for reaction within the hot flame zone. Thermal NO_x is typically controlled by reducing the peak and average flame temperatures. If the temperature or the concentration of oxygen or nitrogen can be reduced quickly after combustion, thermal NO_x formation can be suppressed or “quenched.”

- **Fuel NO_x**: Formed by the oxidation of fuel-bound nitrogen to NO_x during combustion. Nitrogen found in fuels such as coal and residual oils is typically bound to the fuel as part of the organic compounds in the fuel. The rate of fuel NO_x formation is strongly affected by the mixing rate of the fuel and air, and by the oxygen concentration. Although fuel NO_x levels increase with increasing fuel nitrogen content, the increase is not proportional. In general, the control strategy for reducing fuel NO_x formation involves increasing the fuel-to-air ratio. The fuel-bound nitrogen is released in a reducing atmosphere as molecular nitrogen (N_2) rather then being oxidized to NO_x. As with thermal NO_x, controlling excess oxygen is an important part of controlling fuel NO_x formation.

- **Prompt NO_x**: Formed in the combustion system through the reaction of hydrocarbon fragments and atmospheric nitrogen. The name reflects the fact that prompt NO_x is formed very early in the combustion process. The formation of prompt NO_x is weakly dependent on temperature and is significant only in very fuel-rich flames. It is not possible to quench prompt NO_x formation, as it is for thermal NO_x formation.

The traditional parameters leading to complete fuel combustion (high temperatures, long residence time, and high turbulence or mixing) all tend to **increase** the rate of NO_x formation.

2.2.2 HOW ARE NITROGEN OXIDES FORMED IN STATIONARY NONCOMBUSTION SOURCES?

Stationary noncombustion sources include various chemical processes, such as nitric acid and explosives manufacturing. In these processes, the formation of NO_x generally results from nitrogen compounds used or produced in chemical reactions.

2.2.3 WHAT CHARACTERISTICS OF NITROGEN OXIDES DETERMINE THE TYPE OF AIR POLLUTION CONTROL DEVICE USED FOR EMISSIONS CONTROL?

Characteristics of nitrogen oxides that impact the effectiveness of specific air pollution control devices include:

- NO_x can be chemically reduced by reburning using natural gas. NO_x can also be reduced by injecting ammonia or urea at the proper temperature with or without a catalyst.

- The quantity of NO_x formed during combustion depends on: the quantity of nitrogen and oxygen available; temperature; level of mixing; and the time for reaction. Management of these parameters can form the basis of control strategies involving process control and burner design (low NO_x burners and flue gas recirculation).

2.3 SULFUR DIOXIDE (SO_2)

2.3.1 HOW IS SULFUR DIOXIDE FORMED?

Sulfur oxides, primarily SO_2 and sulfur trioxide (SO_3), are formed whenever any material that contains sulfur is burned. From 95 to 100 percent of the total sulfur oxides emissions are in the form of SO_2, which is formed during combustion via the following reaction:

$$S + O_2 \rightarrow SO_2 \qquad (12.2\text{-}1)$$

2.3.2 WHAT CHARACTERISTICS OF SULFUR DIOXIDE DETERMINE THE TYPE OF AIR POLLUTION CONTROL DEVICE USED FOR EMISSIONS CONTROL?

Characteristics of SO_2 that impact the effectiveness of specific air pollution control devices include:

- Sulfur can sometimes be removed from fuel prior to combustion. This may be a cost effective way to reduce SO_2 formation.

- SO_2 is chemically reactive. Therefore, control techniques that reduce pollutant levels via chemical reaction (such as wet acid gas scrubbers and spray dryer absorbers) are appropriate. Also, it can be removed by fluidized limestone bed combustion.

- Formation of SO_2 occurs early in the primary flame and will occur even in fuel-rich flames. As a result, combustion control techniques are not applicable to reduce SO_2 emissions.

- Formation of SO_3 is found to occur only in fuel-rich mixtures and can be influenced by control of combustion conditions.

2.4 VOLATILE ORGANIC COMPOUNDS (VOC)

2.4.1 HOW ARE VOLATILE ORGANIC COMPOUNDS FORMED?

The class of air pollutants referred to as volatile organic compounds includes hundreds of individual compounds, each with its own chemical and physical properties. VOC are emitted from combustion processes, industrial operations, solvent evaporation, and a wide variety of other sources.

2.4.2 WHAT CHARACTERISTICS OF VOLATILE ORGANIC COMPOUNDS DETERMINE THE TYPE OF AIR POLLUTION CONTROL DEVICE USED FOR EMISSIONS CONTROL?

Characteristics of VOC that impact the effectiveness of specific air pollution control devices include:

- Most VOC are adsorbable and may be collected by concentration on the surface of a liquid or solid.

- VOC are combustible and may be oxidized by thermal or catalytic incineration.

2.5 PARTICULATE MATTER (PM)

2.5.1 HOW IS PARTICULATE MATTER FORMED?

Particulate matter can be formed as the result of three processes:

- Materials handling or processing (e.g., crushing or grinding ores, loading bulk materials, sanding of wood, abrasive cleaning [sandblasting]);

- Combustion can emit particles of noncombustible ash or incompletely burned materials; and

- Gas conversion reactions or condensation in the atmosphere.

2.5.2 WHAT CHARACTERISTICS OF PARTICULATE MATTER DETERMINE THE TYPE OF AIR POLLUTION CONTROL DEVICE USED FOR EMISSIONS CONTROL?

Characteristics of PM that impact the effectiveness of specific air pollution control devices include:

- Particle size and size distribution;
- Particle shape;
- Particle density;
- Stickiness;
- Corrosivity;
- Condensation temperature;
- Reactivity; and
- Toxicity.

You must also consider these characteristics of the flue gas stream:

- Gas flow rate;
- Particulate loading;
- Pressure;
- Temperature;
- Viscosity;
- Humidity;
- Chemical composition; and
- Flammability.

2.6 CARBON MONOXIDE (CO)

2.6.1 HOW IS CARBON MONOXIDE FORMED?

During the combustion of any carbonaceous fuel, CO can be formed as the result of two mechanisms:

- **Incomplete combustion**. The burning of carbonaceous fuels is a complex chemical process. Carbon monoxide formed as the first step in the combustion process is then converted to carbon dioxide (CO_2) by combustion with oxygen at temperatures greater than 1160°F. When less than the stoichiometric amount of oxygen is present, CO is the final product of the reaction.

- **High-temperature dissociation of CO_2**. The bond energy for CO_2 is moderately low. At high temperatures CO_2 easily dissociates to form CO and oxygen (O_2).

At elevated temperatures, an increase in oxygen concentration tends to decrease CO levels not only by allowing for complete combustion, but because reaction rates increase with temperature, increasing the chance for collision between CO and O_2 molecules.

2.6.2 WHAT CHARACTERISTICS OF CARBON MONOXIDE DETERMINE THE TYPE OF AIR POLLUTION CONTROL DEVICE USED FOR EMISSIONS CONTROL?

Characteristics of carbon monoxide that impact the effectiveness of specific air pollution control devices include:

- The quantity of CO formed during combustion depends on: quantity of oxygen available; temperature; level of mixing; and the time for reaction. Management of these parameters can form the basis of control strategies involving process control and burner design.

- CO is combustible and can be oxidized to CO_2.

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3

CONTROL TECHNIQUES FOR CRITERIA POLLUTANTS

A variety of practices and equipment are applied either individually or in combination, to reduce the emissions of criteria pollutants. In general, these techniques can be classified into:

- **Process modifications**. These are changes made to the chemical, physical, or thermal process. Process modifications include:
    - Substitution of raw materials. For example, a facility could change the solvent used in a chemical process to reduce VOC emissions.
    - Substitution of fuels. For example, an electrical utility could switch to coal with a lower sulfur content, or use a pre-processed or alternative fuel.
    - Modification of the combustion unit or changing the conditions within the combustion unit. For example, the temperature profile in a boiler can be controlled to limit the formation of nitrogen oxides by the application of combustion unit modifications such as low NO_x burners.
- **Post-process modifications**. Also referred to as “end-of-pipe” or “tailpipe” modifications, these techniques are applied downstream of the process, after the flue gas has passed through the combustion or reaction unit. For example, ammonia can be injected into the post-combustion flue gas stream to reduce NO_x emissions.

3.1 HOW ARE APPROPRIATE AIR POLLUTION CONTROL DEVICES SELECTED?

Selection of the appropriate air pollution control device may be based on the following criteria:

- The physical and chemical characteristics of the pollutant. For example, particulate (solid) matter pollutants are controlled by different techniques and equipment than gaseous pollutants. Also, the particle shape and size, as well as chemical reactivity, abrasiveness, and toxicity of PM pollutants must be considered.

- Gas stream characteristics such as volumetric flow rate, temperature, humidity, density, viscosity, toxicity, or combustibility may limit the applicability of a specific APCD in some facilities.

- Control efficiency of the device. Federal, state, or local regulations may dictate specific emission limits for pollutants based on control efficiency.

- Requirements for handling and disposal of collected waste. For example, wet scrubber installations have to consider treatment of wastewater and dry scrubbers produce quantities of dry fine particulate that must be disposed of.

- Siting characteristics such as available space; ambient conditions; availability of utilities such as power and water; availability of ancillary system facilities such as waste treatment and disposal.

- Economic considerations:

    - Capital costs including equipment costs, installation costs, and engineering fees;

    - Operating costs including fuel, treatment chemicals, utilities, and maintenance; and

    - Expected equipment lifetime.

An air pollution control device or process charge selected to reduce emissions of one pollutant can result in increased emissions of another pollutant. For example, increasing the air-to-fuel ratio (i.e., increasing the amount of oxygen available during combustion) is an effective mechanism to decrease CO emissions, but it dramatically increases NO_x emissions. Care must be taken to ensure that the entire emission control system provides adequate control of all emissions. Selection of APCDs is normally made on flue gas stream-specific characteristics, pollutant characteristics, and desired control efficiency.

3.2 CONTROL OF NITROGEN OXIDES EMISSIONS

3.2.1 WHAT PROCESS AIR POLLUTION CONTROL DEVICES ARE TYPICALLY USED TO CONTROL NITROGEN OXIDES EMISSIONS?

Process controls typically used to control NO_x emissions include fuel switching and fuel denitrification.

Fuel Switching

Conversion to a fuel with a lower nitrogen content or one that burns at a lower temperature may result in a reduction of NO_x emissions. Combustion of natural gas or distillate oils tends to result in lower NO_x emissions than is the case for coal or heavy fuel oils. While fuel switching may be an attractive alternative from the standpoint of NO_x emission reductions, technical constraints and the availability and costs of alternative fuels are major considerations in determining the viability of fuel switching. Moreover, fuel switching may result in greater emissions of other criteria pollutants.

Fuel Denitrification

Fuel denitrification of coal or heavy oils could, in principle, be used to control fuel NO_x formation. Denitrification currently occurs as a side benefit of fuel pretreatment to remove other pollutants, such as pretreatment of oil by desulfurization and chemical cleaning, or solvent refining of coal for ash and sulfur removal. The low denitrification efficiency and high costs of these processes do not make them attractive on the basis of NO_x control alone, but they may prove cost effective on the basis of total environmental impact.

3.2.2 WHAT COMBUSTION AIR POLLUTION CONTROL DEVICES ARE TYPICALLY USED TO CONTROL NITROGEN OXIDES EMISSIONS?

NO_x reduction mechanisms applied during the combustion process include controlling the rate of the fuel-air mixing, reducing oxygen availability in the initial (primary) combustion zone, and reducing peak flame temperatures. These include:

- Low NO_x burners (refer to Section 4.3);
- Natural gas burner/reburn (refer to Section 4.4);
- Water/stream injection (refer to Section 4.5);

- Staged combustion (refer to Section 4.6);
- Flue gas recirculation (refer to Section 4.7);
- Low excess air (refer to Section 4.8); and
- Staged overfire air (refer to Section 4.9).

3.2.3 WHAT POST-PROCESS AIR POLLUTION CONTROL DEVICES ARE TYPICALLY USED TO CONTROL NITROGEN OXIDES EMISSIONS?

Post-process controls are techniques applied downstream of the combustion unit. In post-process control, NO_x is reduced to nitrogen and water through a series of reactions with a chemical agent injected into the flue gas. These emission control techniques include:

- Selective catalytic reduction (refer to Section 4.1); and
- Selective noncatalytic reduction (refer to Section 4.2).
- Nonselective catalytic reduction (refer to Section 4.10).

Table 12.3-1 presents control efficiencies for the various APCDs used to reduce nitrogen oxide emissions. The table presents average, maximum, and minimum control efficiencies reported in the references by each unique combination of emission source and control device. Refer to Appendix D for a complete description of how the data were compiled and presented. Appendix D also contains tables that present control efficiencies reported in the references for control devices not evaluated in this document.

3.3 CONTROL OF SULFUR DIOXIDE EMISSIONS

3.3.1 WHAT PROCESS AIR POLLUTION CONTROL DEVICES ARE TYPICALLY USED TO CONTROL SULFUR DIOXIDE EMISSIONS?

Process controls typically used to control SO_2 emissions include fuel switching, coal washing, coal gasification and liquefaction, desulfurization of oil and natural gas, and fluidized bed combustion.

Fuel Switching

Approximately two-thirds of the sulfur dioxide emitted in the United States are from coal-fired power plants. Many coal-fired facilities attempt to reduce these emissions by switching to coal with a lower sulfur content, such as subbituminous coal which generally contains less sulfur than bituminous coal.

Coal Washing

Much of the sulfur in coal is in pyrite (FeS_2) or in mineral sulfate form, much of which can be removed by washing or other physical cleaning processes. However, disposal of the solid or liquid wastes formed during these processes can be difficult and/or expensive.

Coal Gasification and Liquefaction

Organic sulfur, which is part of the molecular structure of the coal, cannot be removed by washing or other physical cleaning processes. Chemical desulfurization of organic sulfur from coal is extremely expensive. Coal gasification and liquefaction can remove much of the organic sulfur, but results in a substantial loss of total available heating value.

Desulfurization of Oil and Natural Gas

The sulfur in crude oils and natural gas can be removed easily and economically and the elemental sulfur recovered as a by-product can be sold as a raw material. The steps in the desulfurization of oil or natural gas are:

$$R\text{-}S + H_2 \rightarrow H_2S + R \quad \text{(where R represents any organic group)} \qquad (12.3\text{-}1)$$

$$H_2S + {}^3/_2\, O_2 \rightarrow H_2O + SO_2 \qquad (12.3\text{-}2)$$

$$2H_2S + SO2 \rightarrow 2H_2O + 3S \qquad (12.3\text{-}3)$$

$$2H_2S + SO_2 \rightarrow 2H_2O + 3S \qquad (12.3\text{-}4)$$

Fluidized Bed Combustion

Also, combustion of crushed coal in a bed of a sorbent material (fluidized-bed combustion) can reduce SO_2 emissions. Sulfur dioxide in the coal reacts with limestone or dolomite in the bed to form gypsum.

3.3.2 WHAT POST-PROCESS AIR POLLUTION CONTROL DEVICES ARE TYPICALLY USED TO CONTROL SULFUR DIOXIDE EMISSIONS?

Dry and wet scrubbing are the most common technologies to desulfurize flue gas. Slurries of sorbent and water react with SO_2 in the flue gas. Refer to Sections 4.11 through 4.13.

Table 12.3-2 presents control efficiencies for the various APCDs used to reduce SO_2 emissions. This table presents average, maximum, and minimum control efficiencies reported in the references by each unique combination of emission source and control device. Refer to Appendix D for a complete description of how the data are compiled and presented. For those wanting additional information, Appendix D also presents control efficiencies reported in the references for control devices not evaluated in this document.

3.4 CONTROL OF VOLATILE ORGANIC COMPOUNDS

3.4.1 WHAT PROCESS AIR POLLUTION CONTROL DEVICES ARE TYPICALLY USED TO CONTROL VOLATILE ORGANIC COMPOUNDS EMISSIONS?

Typical strategies are:

- Change of coating formulation, such as conversion to water-based paint;
- Change from a VOC-based coating to a non-liquid coating such as powder coat; and
- Change to coating methods that increase transfer efficiency and reduce total coatings used per application.

3.4.2 WHAT POST-PROCESS AIR POLLUTION CONTROL DEVICES ARE TYPICALLY USED TO CONTROL VOLATILE ORGANIC COMPOUNDS EMISSIONS?

Typical post-process control devices of VOC are:

- Carbon adsorber (refer to Section 4.14);
- Incinerator (refer to Sections 4.15 through 4.17);
- Floating-roof storage tank (refer to Section 4.18);
- Vapor capture device during tank filling; and

- Fluid capture, recycle, and reuse.

Table 12.3-3 presents control efficiencies for the various APCDs used to reduce VOC emissions. This table presents average, maximum, and minimum control efficiencies reported in the references by each unique combination of emission source and control device. Refer to Appendix D for a complete description of how the data are compiled and presented. Appendix D also contains tables that present control efficiencies reported in the references for control devices not evaluated.

Note: Many VOC emission sources are processes that are not enclosed or contained and the VOC are emitted into the ambient work area. Before the emissions can be routed to a control device, they must first be captured. There are many types of capture systems (a laboratory hood is a good example) and they seldom capture 100% of the emissions. Although the capture efficiency of a system does not always affect the control efficiency of a downstream control device, it does affect the estimate of overall emissions reduction and, thus, the emissions estimate. Therefore, inventory preparers should be aware that, for some processes, not all of the VOCs generated are captured and controlled. Where a capture system is used, they should talk to facility personnel to get an idea of the efficiency of the system. The questions provided in Section 1.4 about control devices can be used as a guide for obtaining information about capture systems.

3.5 CONTROL OF PARTICULATE MATTER

3.5.1 WHAT PROCESS AIR POLLUTION CONTROL DEVICES ARE TYPICALLY USED TO CONTROL PARTICULATE MATTER EMISSIONS?

Process controls typically used to control particulate matter emissions include fuel switching, coal cleaning, and good combustion practices.

Fuel Switching

Fuel type has a great impact on particulate matter emissions. PM emissions can be reduced by fuel substitution. Coal and fuel oil contain a variety of noncombustible minerals and mineral oxides that are collectively referred to as ash. In terms of fuel composition, ash content of fuel is the major factor in determining PM emissions: the higher the ash content, the higher the amount of PM emitted from combustion. Fuel substitution can have a significant impact on PM emissions. Reductions in emissions of PM_{10} and $PM_{2.5}$ resulting from fuel substitution are shown in Tables 12.3-4 and 12.3-5.

In many cases, switching fuels will impact more than one type of pollutant. For example, substituting natural gas for coal to reduce PM emissions can also effectively reduce sulfur dioxide and nitrogen oxides emissions. However, switching to low sulfur coal to reduce sulfur dioxide emissions can increase PM emissions.

Coal Cleaning

Physical cleaning of coal can be used to reduce mineral matter. This decreases PM emissions and increases the energy content of the coal, but may not always be cost effective.

Good Combustion Practices

Incomplete combustion can result in increased particulate emissions due to unburned carbon material released as particulate matter. Particulate emissions can be controlled by following "good combustion practices" that include design and operational elements such as:

- Control of the amount and distribution of excess air in the combustion zone;
- Adequate turbulence in the combustion zone to ensure good mixing;
- High temperature zone to ensure complete burning; and
- Sufficient residence time (1 - 2 seconds) at the high temperature.

These good combustion practices also limit CO and dioxin/furan emissions, but can increase the formation of NO_x.

3.5.2 WHAT POST-PROCESS AIR POLLUTION CONTROL DEVICES ARE TYPICALLY USED TO CONTROL PARTICULATE MATTER EMISSIONS?

Four classes of control equipment are used to remove PM from gas streams:

- Mechanical collectors such as cyclones (refer to Section 4.19);
- Electrostatic precipitators (refer to Section 4.20);
- Fabric filters, also referred to as baghouses (refer to Section 4.21); and
- Wet PM scrubbers (refer to Section 4.22).

Table 12.3-6 presents CE for the various APCDs used to reduce PM emissions. This table presents average, maximum, and minimum CE reported in the references by each unique combination of emission source and control device.

3.6 CONTROL OF CARBON MONOXIDE

Process controls typically used to control CO emissions include fuel switching, good combustion practices; and CO catalyst.

3.6.1 WHAT PROCESS AIR POLLUTION CONTROL DEVICES ARE TYPICALLY USED TO CONTROL CARBON MONOXIDE EMISSIONS?

Fuel Switching

Fuel substitution can be used as a technique to reduce CO emissions because CO emissions from coal-fired combustion are usually higher than those from the combustion of oil or natural gas. Note, however that fuel substitution may result in higher emissions of other pollutants.

Good Combustion Practices

CO emissions can be controlled by following “good combustion practices” because CO emissions from well-operated boilers are usually quite low. Good combustion practices include:

- Control of the amount and distribution of excess air in the combustion zone;
- Adequate turbulence in the combustion zone to ensure good mixing;
- High temperature zone to ensure complete burning; and
- Sufficient residence time (1 - 2 seconds) at the high temperature.

CO Catalysts

CO oxidation catalysts are typically used on gas turbines to control CO emissions, especially turbines that use steam injection which can increase CO and unburned hydrocarbons in the exhaust. CO catalysts are also being used to reduce gaseous organic compounds, including organic HAPs emissions.

3.6.2 WHAT POST-PROCESS COMBUSTION AIR POLLUTION CONTROL DEVICES ARE TYPICALLY USED TO CONTROL CARBON MONOXIDE EMISSIONS?

Post-process techniques to reduce CO emissions are based on treatment of the exhaust gas to oxidize CO to CO_2. Air pollution control devices used are:

- Thermal oxidizers (refer to Section 4.15);
- Catalytic oxidizers (refer to Section 4.16); and
- Flares (refer to Section 4.17).

The most critical operating parameter, in terms of limiting CO emissions, is the air-to-fuel ratio. There must be sufficient levels of oxygen available to ensure complete combustion of CO to CO_2.

Some catalysts that reduce emissions of CO may decrease SO_2 emissions and increase in NO_x emissions.

Table 12.3-7 presents control efficiencies for the various APCDs used to reduce CO emissions. This table presents average, maximum, and minimum control efficiencies reported in the references by each unique combination of emission source and control device.

TABLE 12.3-1

CONTROL EFFICIENCIES (%) FOR NO$_x$ BY SOURCE CATEGORY AND CONTROL DEVICE TYPE

Process	Operation	Control Device Type	Average CE (%)	Reference	CE Range (%) Minimum Value	CE Range (%) Maximum Value	Reference
Chemical Manufacturing	Acrylonitrile-Incinerator Stacks	Selective Non-catalytic Reduction	80	a			
Fuel Combustion-Coal	Boiler	Flue Gas Recirculation			5	45	b
Fuel Combustion-Coal	Boiler	Low Excess Air			5	30	
Fuel Combustion-Coal	Boiler	Low NO$_x$ Burners			35	55	f
Fuel Combustion-Coal	Boiler	Natural Gas Burners/Reburn			50	70	c
Fuel Combustion-Coal	Boiler	Overfire Air			5	30	b
Fuel Combustion-Coal	Boiler	Selective Catalytic Reduction			63	94	d
Fuel Combustion-Coal	Boiler	Selective Non-catalytic Reduction	90	b			
Fuel Combustion-Distillate Oil	Boiler	Flue Gas Recirculation			45*	55*	f
Fuel Combustion-Distillate Oil	Boiler	Low Excess Air			2	19	
Fuel Combustion-Distillate Oil	Boiler	Overfire Air			20	45	f
Fuel Combustion-Distillate Oil	Boiler	Selective Catalytic Reduction				90	b
Fuel Combustion-Coal		Low-NO$_x$ Burner with Selective Non-catalytic Reduction			50	80	f

* Average of widely varying values.

TABLE 12.3-1

CONTROL EFFICIENCIES (%) FOR NO_x BY SOURCE CATEGORY AND CONTROL DEVICE TYPE (CONTINUED)

Process	Operation	Control Device Type	Average CE (%)	Reference	CE Range (%)		Reference
					Minimum Value	Maximum Value	
Fuel Combustion-Coal		Low -NO_x Burner with Overfire Air and Selective Catalytic Reduction			85	95	f
Fuel Combustion Coal	Boiler	Low -NO_x Burner with Overfire Air			40	60	f
Fuel Combustion-Municipal Waste	Boiler	Selective Catalytic Reduction	69	b		80	a
Fuel Combustion-Municipal Waste	Incinerator	Selective Non-catalytic Reduction			30	65	a
Fuel Combustion-Natural Gas	Boiler	Flue Gas Recirculation			49	68	b
Fuel Combustion-Natural Gas	Boiler	Low Excess Air			0	31	b
Fuel Combustion-Natural Gas	Boiler	Low NO_x Burners			40	85	e
Fuel Combustion-Natural Gas	Boiler	Overfire Air	60	b	13	73	b
Fuel Combustion-Natural Gas	Boiler	Selective Catalytic Reduction			80	90	e
Fuel Combustion-Natural Gas	Boiler	Selective Non-catalytic Reduction			35	80	b
Fuel Combustion-Natural Gas	Gas Turbines	Selective Catalytic Reduction			60	96	g
Fuel Combustion-Natural Gas	Gas Turbines	Water or Steam Injection			60	94	g
Fuel Combustion-Natural Gas	Reciprocating Engines	Selective Non-catalytic Reduction			80	90	e
Fuel Combustion- Natural Gas	Gas Turbines	Staged Combustion			50	80	g
Fuel Combustion-Natural Boiler Gas	Boiler	Low-NO_x Burner with Overfire Air			40	50	f

TABLE 12.3-1

CONTROL EFFICIENCIES (%) FOR NO_x BY SOURCE CATEGORY AND CONTROL DEVICE TYPE (CONTINUED)

Process	Operation	Control Device Type	Average CE (%)	Reference	CE Range (%)		Reference
					Minimum Value	Maximum Value	
Fuel Combustion-Residual Oil	Boiler	Flue Gas Recirculation	21	b	2	31	b
Fuel Combustion-Residual Oil	Boiler	Low Excess Air			5	31	b
Fuel Combustion-Residual Oil	Boiler	Overfire Air			24	47	b
Fuel Combustion-Residual Oil	Boiler	Selective Catalytic Reduction			70	80	b
Fuel Combustion-Residual Oil	Boiler	Selective Non-catalytic Reduction			35	70	b
Fuel Combustion-Utility Oil or Natural Gas	Boiler	Flue Gas Recirculation			40	65	b
Fuel Combustion-Wood	Boiler	Selective Non-catalytic Reduction			50	70	a
Mineral Products Industry	Glass Flue	Selective Non-catalytic Reduction			50	75	a
Petroleum Industry	Process Heaters	Selective Catalytic Reduction	90	b			
Petroleum Industry	Process Heaters	Selective Non-catalytic Reduction			35	70	b

TABLE 12.3-1

CONTROL EFFICIENCIES (%) FOR NO$_X$ BY SOURCE CATEGORY AND CONTROL DEVICE TYPE (CONTINUED)

[a] Air & Waste Management Association. 1992. *Air Pollution Engineering Manual*. Anthony J. Buonicore and Wayne T. Davis, editors, Van Nostrand Reinhold, New York, New York.

[b] EPA. 1992b. *Summary of NO$_x$ Control Techniques and their Availability and Extent of Application.* U.S. Environmental Protection Agency, EPA 450/3-9200094.

[c] Pratapas, J. and J. Bluestein. 1994. Natural Gas Reburn: Cost Effective NO$_x$ Control. *Power Engineering,* May 1994.

[d] EPA. 1997. *Performance of Selective Catalytic Reduction on Coal-Fired Steam Generating Units*. U.S. Environmental Protection Agency, Acid Rain Division.

[e] EPA. 1995. *Compilation of Air Pollutant Emission Factors, Volume I: Stationary Point and Area Sources, Fifth Edition, AP-42. Supplements A, B, C, D, and E*. U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Research Triangle Park, North Carolina.

[f] EPA, 1994a. Alternative Control Techniques Document - NO$_x$ Emissions from Utility Boilers. U.S. Environmental Protection Agency, EPA-453/R-94-023. http://www.epa.gov/ttn/catc/dir1/nox_act.txt

[g] EPA, 1994b. Alternative Control Techniques Document - NO$_x$ Emissions from Stationary Gas Turbines. U.S. Environmental Protection Agency, EPA-453/R-93-007. http://www.epa.gov/ttn/catc/dir1/nox_act.txt

TABLE 12.3-2

CONTROL EFFICIENCIES (%) FOR SO_2 BY SOURCE CATEGORY AND CONTROL DEVICE TYPE

Process	Operation	Control Device Type	Average CE (%)[a]	Reference	CE Range (%)[a]		Reference
					Minimum Value	Maximum Value	
Chemical Manufacturing	Boiler	Wet Acid Gas Scrubber			90	99	b
Chemical Manufacturing	Sulfuric Acid Industry	Scrubber, General			60	99	b
Fuel Combustion-Coal	Boiler	Wet Acid Gas Scrubber			80	99	c
Fuel Combustion-Coal	Boiler	Spray Dryer Absorber[d]			70	90	c
Fuel Combustion-Lignite	Boiler	Wet Acid Gas Scrubber			90		c
Fuel Combustion-Lignite-Municipal Waste	Incinerator	Spray Dryer Absorber	50	c		95	c

[a] Reported control efficiencies are for sulfur oxides (SO_x).

[b] EPA. 1981. *Control Techniques for Sulfur Oxide Emissions from Stationary Sources. Second Edition*. U.S. Environmental Protection Agency, EPA 452/3-81-004.

[c] Air & Waste Management Association. 1992. *Air Pollution Engineering Manual*. Anthony J. Buonicore and Wayne T. Davis, editors, Van Nostrand Reinhold, New York, New York.

[d] Calcium hydroxide slurry, vaporizes in spray vessel.

TABLE 12.3-3

CONTROL EFFICIENCIES (%) FOR VOC BY SOURCE CATEGORY AND CONTROL DEVICE TYPE

Process	Operation	Control Device Type	Average CE (%)	Reference	CE Range (%) Minimum Value	CE Range (%) Maximum Value	Reference
Automobile Manufacturing	Bake Oven Exhaust	Thermal Incinerator			90		a
Can Coating	Exterior Coating	Catalytic Incinerator	90	a			
Can Coating	Exterior Coating	Thermal Incinerator	90	a			
Can Coating	Interior Coating	Carbon Adsorber	90	a			
Can Coating	Interior Coating	Catalytic Incinerator	90	a			
Can Coating	Interior Coating	Thermal Incinerator	90	a			
Chemical Manufacturing	Absorber Vent	Catalytic Incinerator			95	97	a
Chemical Manufacturing	Absorber Vent	Thermal Incinerator	99.9	a			
Chemical Manufacturing	Acrylonitrile-Absorber Vent	Catalytic Incinerator			95	97	a
Chemical Manufacturing	Acrylonitrile-Absorber Vent	Thermal Incinerator	99.9	a			
Chemical Manufacturing	Reactor Vents	Carbon Adsorber	97	a			
Chemical Manufacturing	Residue Tower Bottoms	Thermal Incinerator	99.9	a			
Chemical Manufacturing	SOCMI Reactor	Carbon Adsorber				95	a
Chemical Manufacturing	Waste Gas Column	Flares			98	99	a

TABLE 12.3-3

CONTROL EFFICIENCIES (%) FOR VOC BY SOURCE CATEGORY AND CONTROL DEVICE TYPE (CONTINUED)

Process	Operation	Control Device Type	Average CE (%)	Reference	CE Range (%) Minimum Value	CE Range (%) Maximum Value	Reference
Degreasing- In-line Cleaner	General	Carbon Adsorber				65	a
Degreasing- Open Top Vapor Cleaner	General	Carbon Adsorber				39	a
Dry Cleaning	Petroleum Solvent	Carbon Adsorber			95		a
Fabric Coating	General	Carbon Adsorber	95	b			
Fabric Coating	General	Thermal Incinerator	95	b			
Food Industry	Spiral Ovens	Catalytic Incinerator	90	a			
Food Industry	Whiskey Manufacturing/ Warehousing	Carbon Adsorber	85	b			
General	Can Production	Thermal Incinerator				90	b
General	General	Carbon Adsorber			95	99	c
General	General	Catalytic Incinerator			95	99	c
General	General	Flares	98	c			
General	General	Thermal Incinerator				99	c

TABLE 12.3-3

CONTROL EFFICIENCIES (%) FOR VOC BY SOURCE CATEGORY AND CONTROL DEVICE TYPE (CONTINUED)

Process	Operation	Control Device Type	Average CE (%)	Reference	CE Range (%)		Reference
					Minimum Value	Maximum Value	
General	General	Thermal Incinerator			98		d
General	Natural Gas Processing	Flares			96	99	b
General	Natural Gas Processing	Floating Roof Tank			60	99	b
Graphic Arts	Drying Ovens	Catalytic Incinerator			90	98	a
Graphic Arts	Drying Ovens	Thermal Incinerator	99	a			
Graphic Arts	Flexography	Catalytic Incinerator			90	98	a
Graphic Arts	Flexography	Thermal Incinerator			95	98	a
Graphic Arts	Gravure Printing	Carbon Adsorber			95		a
Graphic Arts	Gravure Printing	Thermal Incinerator	99	a	95	99.8	a
Graphic Arts	Heatset Web Offset	Catalytic Incinerator			90	98	a
Graphic Arts	Heatset Web Offset	Thermal Incinerator			95	99.8	a
Graphic Arts	Printing Presses	Carbon Adsorber			75	95	b
Graphic Arts	Printing Presses	Thermal Incinerator	95	b			
Groundwater Treatment	Air Strippers	Carbon Adsorber			75	95	a

TABLE 12.3-3

CONTROL EFFICIENCIES (%) FOR VOC BY SOURCE CATEGORY AND CONTROL DEVICE TYPE (CONTINUED)

Process	Operation	Control Device Type	Average CE (%)	Reference	CE Range (%) Minimum Value	CE Range (%) Maximum Value	Reference
Groundwater Treatment	Air Strippers	Thermal Incinerator			90	98	a
Liquid Storage Tanks	Storage Tanks	Thermal Incinerator			96	99	e
Lithography	Printing Presses	Catalytic Incinerator	90	b			
Lithography	Printing Presses	Thermal Incinerator	90	b			
Magnetic Tape Manufacturing	Drying Ovens	Carbon Adsorber	95	a			
Magnetic Tape Manufacturing	Drying Ovens	Catalytic Incinerator	98	a			
Magnetic Tape Manufacturing	Drying Ovens	Thermal Incinerator	98	a			
Metallurgical Industry	Open Arc Furnaces	Flares	98	e			
Metallurgical Industry	Smelters	Spray Dyer Absorber	90	a			
Mineral Manufacturing	Kilns	Spray Dryer Absorber			95	99	e
Mineral Products Industry	Kilns	Thermal Incinerator	95	e			
Municipal Solid Waste	Landfill	Flares	98	a			

TABLE 12.3-3

CONTROL EFFICIENCIES (%) FOR VOC BY SOURCE CATEGORY AND CONTROL DEVICE TYPE (CONTINUED)

					CE Range (%)		
Process	**Operation**	**Control Device Type**	**Average CE (%)**	**Reference**	**Minimum Value**	**Maximum Value**	**Reference**
Pharmaceutical Industry	Vent Streams	Thermal Incinerator	98	a			
Plywood Manufacturing	General	Thermal Incinerator			90		b
Printing Lines	Flexography	Thermal Incinerator	60	a			
Printing Lines	Letterpress	Thermal Incinerator	95	a			
Printing Lines	Lithography	Thermal Incinerator	95	a			
Printing Lines	Rotogravure Operations	Carbon Adsorber	75	a			
Printing Lines	Rotogravure Operations	Thermal Incinerator	65	a			
Rubber Manufacturing	Blow Down Tanks	Scrubber, General	90	a			
Surface Coating	Bake Oven	Catalytic Incinerator	96	a			
Surface Coating	Bake Oven	Thermal Incinerator	96	a			
Surface Coating	Coating Line	Carbon Adsorber	80	a			
Surface Coating	Curing Oven Exhaust	Thermal Incinerator	90	b			
Surface Coating	Drying Ovens	Carbon Adsorber	95	b			

TABLE 12.3-3

CONTROL EFFICIENCIES (%) FOR VOC BY SOURCE CATEGORY AND CONTROL DEVICE TYPE (CONTINUED)

					CE Range (%)		
Process	**Operation**	**Control Device Type**	**Average CE (%)**	**Reference**	**Minimum Value**	**Maximum Value**	**Reference**
Petroleum Industry	Fixed Roof Tank	Carbon Adsorber	98	b			
Petroleum Industry	Fixed Roof Tank	Vent Recovery System	85	a			
Petroleum Industry	Floating Roof Tank	Vent Recovery System			95	99	a
Petroleum Industry	General	Catalytic Incinerator			95		a
Petroleum Industry	General	Thermal Incinerator			98	99	a
Petroleum Industry	Petroleum Tank Cleaning	Flares	90	b			
Petroleum Industry	Petroleum Tank Cleaning	Thermal Incinerator	98	b			
Petroleum Industry	Petroleum Tank Transfer	Flares			63	81	b
Petroleum Industry	Petroleum Tank Transfer	Thermal Incinerator			68	88	b
Petroleum Industry	Vent Streams	Flares	98	a			
Pharmaceutical Industry	Vent Streams	Carbon Adsorber			95	99	a

TABLE 12.3-3

CONTROL EFFICIENCIES (%) FOR VOC BY SOURCE CATEGORY AND CONTROL DEVICE TYPE (CONTINUED)

					CE Range (%)		
Process	**Operation**	**Control Device Type**	**Average CE (%)**	**Reference**	**Minimum Value**	**Maximum Value**	**Reference**
Surface Coating	Drying Ovens	Thermal Incinerator	95	b			
Surface Coating	Entire Process	Carbon Adsorber	90	a			
Surface Coating	Flatwood Paneling Processes	Thermal Incinerator				94	b
Surface Coating	General	Carbon Adsorber			90		a
Surface Coating	General	Thermal Incinerator	90	a			
Surface Coating	Magnet Wire Production	Thermal Incinerator	90	a	90		b
Surface Coating	Metal Coating	Carbon Adsorber	90	a			
Surface Coating	Metal Coil Coating	Catalytic Incinerator	95	a	90		a
Surface Coating	Metal Coil Coating	Thermal Incinerator			80	90	b
Surface Coating	Metal Coil Coating	Thermal Incinerator	95	a	90		a
Surface Coating	Paper film	Thermal Incinerator	95	a			
Surface Coating	Paper film/foil	Carbon Adsorber	95	b			

TABLE 12.3-3

CONTROL EFFICIENCIES (%) FOR VOC BY SOURCE CATEGORY AND CONTROL DEVICE TYPE (CONTINUED)

Process	Operation	Control Device Type	Average CE (%)	Reference	CE Range (%) Minimum Value	CE Range (%) Maximum Value	Reference
Surface Coating	Paper film/foil	Thermal Incinerator	98	b			
Surface Coating	Polymeric Coating	Carbon Adsorber	95	a			
Surface Coating	Polymeric Coating	Catalytic Incinerator	98	a			
Surface Coating	Polymeric Coating	Thermal Incinerator	98	a			
Surface Coating	Spray Booth	Carbon Adsorber	90	a			
Waste Solvent Reclamation	Solvent Recovery	Carbon Adsorber				95	a
Waste Solvent Reclamation	Solvent Recovery	Floating Roof Tank				98	a
Waste Treatment and Land Disposal	General	Flares	98	a			
Wastewater Industry	Treatment System	Carbon Adsorber			90	99	a
Wastewater Industry	Water Filtration	Carbon Adsorber			90	99	e

[a] Air & Waste Management Association. 1992. *Air Pollution Engineering Manual.* Anthony J. Buonicore and Wayne T. Davis, editors, Van Nostrand Reinhold, New York, New York.

[b] EPA. 1992a. *Control Techniques for Volatile Organic Compound Emissions from Stationary Sources*. U.S. Environmental Protection Agency, EPA 453/R-92-018.

[c] EPA. 1991. *Control Technologies for HAPs*. U.S. Environmental Protection Agency.

[d] EPA. 1998. *Stationary Source Control Techniques Document for Fine Particulate Matter*. U.S. Environmental Protection Agency, EPA, 452/R-97-001

[e] EPA. 1995. *Compilation of Air Pollutant Emission Factors, Volume I: Stationary Point and Area Sources, Fifth Edition, AP-42. Supplements A, B, C, D, and E*. U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Research Triangle Park, North Carolina.

TABLE 12.3-4

POTENTIAL PM_{10} EMISSION REDUCTIONS WITH FUEL SWITCHING (%)[a]

	Replacement Fuel						
	Industrial				**Utility**		
Original Fuel	**Subbituminous**	**Residual Oil**[b]	**Natural Gas**	**Distillate Oil**[c]	**Subbituminous**	**Residual Oil**[b]	**Natural Gas**
Bituminous Coal	21.4%	62.9%	98.2%	99.0%	21.4%	69.5%	99.3%
Subbituminous Coal	--	52.8%	97.7%	98.8%	--	61.2%	99.2%
Residual Oil[b]	–	–	95.1%	97.4%	--	--	97.9%

[a] Source: EPA. 1998. *Stationary Source Control Techniques Document for Fine Particulate Matter.* U.S. Environmental Protection Agency. EPA 452/R-97-001

[b] Residual Oil includes No. 4, 5, and 6 fuel oil.

[c] Distillate Oil is No. 2 fuel oil.

TABLE 12.3-5

POTENTIAL $PM_{2.5}$ EMISSION REDUCTIONS WITH FUEL SWITCHING (%)[a]

	Replacement Fuel						
	Industrial				**Utility**		
Original Fuel	**Subbituminous**	**Residual Oil**[b]	**Natural Gas**	**Distillate Oil**[c]	**Subbituminous**	**Residual Oil**[b]	**Natural Gas**
Bituminous Coal	21.4%	7.4%	93.1%	99.0%	21.4%	14.8%	97.5%
Subbituminous Coal	--	--	91.2%	98.8%	--	--	96.8%
Residual Oil[b]	–	–	92.5%	99.0%	--	--	97.0%

[a] Source: EPA. 1998. *Stationary Source Control Techniques Document for Fine Particulate Matter*. U.S. Environmental Protection Agency. EPA 452/R-97-001.

[b] Residual Oil includes No. 4, 5, and 6 fuel oil.

[c] Distillate Oil is No. 2 fuel oil.

TABLE 12.3-6

CONTROL EFFICIENCIES (%) FOR PM BY SOURCE CATEGORY AND CONTROL DEVICE TYPE

Process	Operation	Control Device Type	Average CE (%)	Reference	CE Range (%) Minimum Value	CE Range (%) Maximum Value	Reference
Fuel Combustion- Bagasse	Boiler	Mechanical Collector			20	60	a
Fuel Combustion- Bagasse	Boiler	Wet PM Scrubber			90		b
Fuel Combustion- Coal	Boiler	Electrostatic Precipitator	99	b	90	99.9	a
Fuel Combustion- Coal	Boiler	Fabric Filter	99	b	99		a
Fuel Combustion- Coal	Boiler	Mechanical Collector	65	b	90	95	b
Fuel Combustion- Coal	Boiler	Wet PM Scrubber			50	99	b
Fuel Combustion- Coal (anthracite)	Boiler	Electrostatic Precipitator	98.4	c			
Fuel Combustion- Coal (anthracite)	Boiler	Fabric Filter			98.4	99.4	c
Fuel Combustion- Coal (bituminous)	Boiler	Electrostatic Precipitator			96	99.4	c
Fuel Combustion- Coal (bituminous)	Boiler	Fabric Filter			98.3	99.9	c
Fuel Combustion- Lignite	Boiler	Electrostatic Precipitator			95	99.5	a
Fuel Combustion- Lignite	Boiler	Mechanical Collector			60	80	a

TABLE 12.3-6

CONTROL EFFICIENCIES (%) FOR PM BY SOURCE CATEGORY AND CONTROL DEVICE TYPE (CONTINUED)

Process	Operation	Control Device Type	Average CE (%)	Reference	CE Range (%)		Reference
					Minimum Value	Maximum Value	
Fuel Combustion- Wood	Boiler	Electrostatic Precipitator			93	99.8	a, b
Fuel Combustion- Wood	Boiler	Fabric Filter	98	b	95.9	99.9	a
Fuel Combustion- Wood	Boiler	Mechanical Collector			65	95	b
Fuel Combustion- Wood	Boiler	Wet PM Scrubber	90	b	95	99	a
Sewage Sludge Incineration	Boiler	Wet PM Scrubber			60	99	a
Charcoal Industry	Briquetting Operation	Fabric Filter	99	b			
Charcoal Industry	Briquetting Operation	Mechanical Collector	65	b			b
Chemical Manufacturing	Charcoal Production	Fabric Filter	99	a			
Chemical Manufacturing	Charcoal Production	Mechanical Collector	65	a			a
Chemical Manufacturing	Condenser Unit	Mechanical Collector			90	98	b

TABLE 12.3-6

CONTROL EFFICIENCIES (%) FOR PM BY SOURCE CATEGORY AND CONTROL DEVICE TYPE (CONTINUED)

Process	Operation	Control Device Type	Average CE (%)	Reference	CE Range (%)		Reference
					Minimum Value	Maximum Value	
Chemical Manufacturing	Condenser Unit	Scrubbers, General				99	b
Chemical Manufacturing	Condenser Unit	Thermal Incinerator with Wet PM Scrubber	96	b			
Iron and Steel Production	Delsulfurization	Fabric Filter	96.7	c			
Coal Industry	Drying Ovens	Wet PM Scrubber			98	99.9	b
Ferroalloy Industry	Ferroalloy Electric Arc Furnace	Fabric Filter			96.3	98.7	c
Zinc Smelting	Furnace	Fabric Filter	96.3	b			b
Chemical Manufacturing	General	Thermal Incinerator			79	96	c
Fuel Combustion- Wood	General	Wet PM Scrubber			92.1	93.3	c
Fuel Combustion- Wood Bark	General	Wet PM Scrubber			83.8	85.1	c
General	General	Electrostatic Precipitator			95	99.9	d
General	General	Fabric Filter			99		d
General	General	Mechanical Collector			80	95	c
General	General	Wet PM Scrubber	99	c			
Petroleum Industry	General	Electrostatic Precipitator				85	a

TABLE 12.3-6

CONTROL EFFICIENCIES (%) FOR PM BY SOURCE CATEGORY AND CONTROL DEVICE TYPE (CONTINUED)

Process	Operation	Control Device Type	Average CE (%)	Reference	CE Range (%)		Reference
					Minimum Value	Maximum Value	
Iron and Steel Production	Gray Iron Cupolas	Fabric Filter			93.4	93.9	c
Metallurgical Industry	Iron Foundry	Fabric Filter			98	99	a
Metallurgical Industry	Lead Smelters	Electrostatic Precipitator			95	99	a
Metallurgical Industry	Lead Smelters	Fabric Filter			95	99	a
Metallurgical Industry	Lead Smelters	Mechanical Collector			80	90	a
Copper Smelting	Multiple Hearth Roaster	Electrostatic Precipitator	99	c			
Iron and Steel Production	Open Hearth Furnace	Electrostatic Precipitator	99.2	c			
Coke Production	Preheater	Wet PM Scrubber			89	92.9	b
Petroleum Industry	Process Heaters	Mechanical Collector				85	b
Petroleum Industry	Process Heaters	Electrostatic Precipitator				85	b
Soap Industry	Production Line	Mechanical Collector			90		a
Wood Products	Recover Furnace	Electrostatic Precipitator			90	99	a
Wood Products	Recover Furnace	Wet PM Scrubber with Electrostatic Precipitator			85	99	b
Copper Smelting	Reverberatory Smelter	Electrostatic Precipitator	97.2	c			

TABLE 12.3-6

CONTROL EFFICIENCIES (%) FOR PM BY SOURCE CATEGORY AND CONTROL DEVICE TYPE (CONTINUED)

Process	Operation	Control Device Type	Average CE (%)	Reference	CE Range (%)		Reference
					Minimum Value	Maximum Value	
Metallurgical Industry	Roasters	Cold Electrostatic Precipitator	95	a			
Metallurgical Industry	Roasters	Hot Electrostatic Precipitator			20	80	a
Medical Waste Incineration	Rotary Kiln	Fabric Filter				99.9	a
Iron and Steel Production	Sinter Furnace	Electrostatic Precipitator			90	94	c
Copper Smelting	Smelters	Fabric Filter	99	b			
Food Industry	Smokehouses	Wet PM Scrubber	69	b			
Mineral Products Industry	Thermal Dryer	Wet PM Scrubber			98	99.9	b
Phosphate Industry	Thermal Dryer	Electrostatic Precipitator			90	99	b
Phosphate Industry	Thermal Dryer	Wet PM Scrubber			96	99.9	b
Phosphate Industry	Thermal Dryer	Wet PM Scrubber			80	99	b
Polystyrene Production	Thermal Dryer	Mechanical Collector with Fabric Filter				99	b
Soap Industry	Thermal Dryer	Mechanical Collector with Fabric Filter				99	b
Agriculture Industry	Transfer Systems	Fabric Filter			99		a
Petroleum Industry	Vent Streams	Mechanical Collector			90		a

TABLE 12.3-6

CONTROL EFFICIENCIES (%) FOR PM BY SOURCE CATEGORY AND CONTROL DEVICE TYPE (CONTINUED)

[a] Air & Waste Management Association. 1992. *Air Pollution Engineering Manual*. Anthony J. Buonicore and Wayne T. Davis, editors, Van Nostrand Reinhold, New York, New York.

[b] EPA. 1995. *Compilation of Air Pollutant Emission Factors, Volume I: Stationary Point and Area Sources, Fifth Edition, AP-42. Supplements A, B, C, D, and E*. U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Research Triangle Park, North Carolina.

[c] EPA. 1991. *Control Technologies for HAPs*. U.S. Environmental Protection Agency.

[d] EPA. 1998. *Stationary Source Control Techniques Document for Fine Particulate Matter*. U.S. Environmental Protection Agency, EPA 452/R-97-001

TABLE 12.3-7

CONTROL EFFICIENCIES (%) FOR CO BY SOURCE CATEGORY AND CONTROL DEVICE TYPE

Process	Operation	Control Device Type	Average CE (%)	Reference	CE Range (%)		Reference	Comments
					Minimum Value	**Maximum Value**		
Chemical Manufacturing	Catalytic Process for Acrylonitrile	Thermal Incinerator			95		a	
Chemical Manufacturing	Catalytic Process for Acrylonitrile	Catalytic Incinerator			95		a	
Chemical Manufacturing	Catalytic Process for Phthalic Anhydride	Thermal Incinerator				99	a	
Chemical Manufacturing	Condenser Unit	Thermal Incinerator	96	a				
Fuel Combustion- Natural Gas	Incinerator	Thermal Incinerator				90		
General	General	Catalytic Incinerator	90	b				
General	General	Thermal Incinerator			90			
Metallurgical Industry	Open Arc Furnaces	Flare	98	a				
Metallurgical Industry	Furnaces	Flare	98	c				

[a] EPA. 1995. *Compilation of Air Pollutant Emission Factors, Volume I: Stationary Point and Area Sources, Fifth Edition, AP-42. Supplements A, B, C, D, and E.* U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Research Triangle Park, North Carolina.

[b] EPA. 1979. *Control Techniques for Carbon Monoxide Emissions*. U.S. Environmental Protection Agency, EPA 452/3-79-006.

[c] Air and Waste Management Association. 1992. *Air Pollution Engineering Manual*. Anthony J. Buonicore and Wayne T. Davis, editors, Van Nostrand Reinhold, New York, New York.

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4

DESCRIPTIONS OF AIR POLLUTION CONTROL DEVICES

4.1 SELECTIVE CATALYTIC REDUCTION (SCR)

4.1.1 WHAT POLLUTANTS ARE CONTROLLED USING SELECTIVE CATALYTIC REDUCTION?

NO_x is controlled using SCR. SCR is the most developed and widely applied post-process NO_x control technique used today.

4.1.2 HOW DOES SELECTIVE CATALYTIC REDUCTION WORK?

A reducing agent, usually diluted with water, steam, or air, is injected through a grid system into the flue gas stream upstream of a catalyst bed enclosed in a reactor. On the catalyst surface, the reagent reacts with the NO_x to form molecular nitrogen and water. The rate of reaction of the reagent and NO_x is increased by the presence of excess oxygen. The reduction reaction is illustrated in Figure 12.4-1.

Note: SCR is "selective" in that the reagent reacts primarily with NO_x, not with O_2 or other major components of the flue gas.

The performance of an SCR system is influenced by five factors:

- Flue gas temperature;
- Reagent-to-NO_x ratio;
- NO_X concentration at the SCR inlet;
- Space velocity (measure of the volumetric feed capacity of a continuous-flow reactor per unit residence time); and
- Condition of the catalyst.

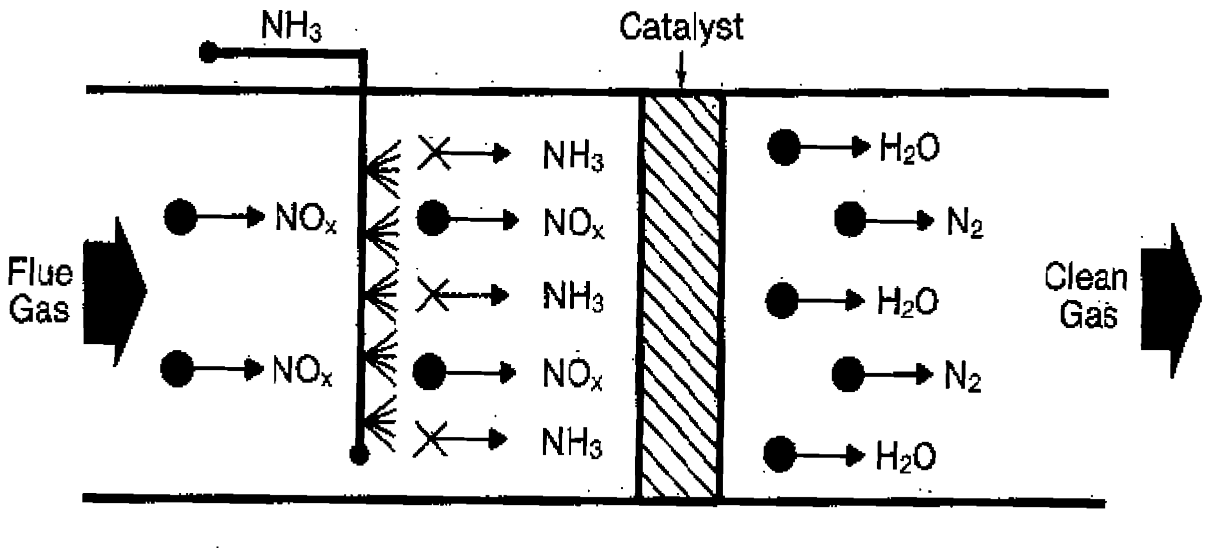

FIGURE 12.4-1. REMOVAL OF NO_x BY SCR (BABCOCK & WILCOX, 1992)

The primary variable affecting NO_x reduction is temperature. Below the optimal temperature range, which depends on the type of catalyst used, the activity of the catalyst is greatly reduced, allowing unreacted reagent to slip through. On the other hand, extreme temperatures can damage the catalyst. Figure 12.4-2 illustrates a typical SCR system.

4.1.3 WHAT REDUCING AGENT IS USED IN SELECTIVE CATALYTIC REDUCTION?

With an appropriate catalyst, ammonia (NH_3) or an ammonia derivative (i.e., urea), could be used as the reducing gas; however, the most commonly used material is NH_3. The reduction reactions for the SCR process are:

$$4NO + 4NH_3 + O_2 \rightarrow 4N_2 + 6H_2O \qquad (12.4\text{-}1)$$

$$2NO_2 + 4NH_3 + O_2 \rightarrow 3N_2 + 6H_2O \qquad (12.4\text{-}2)$$

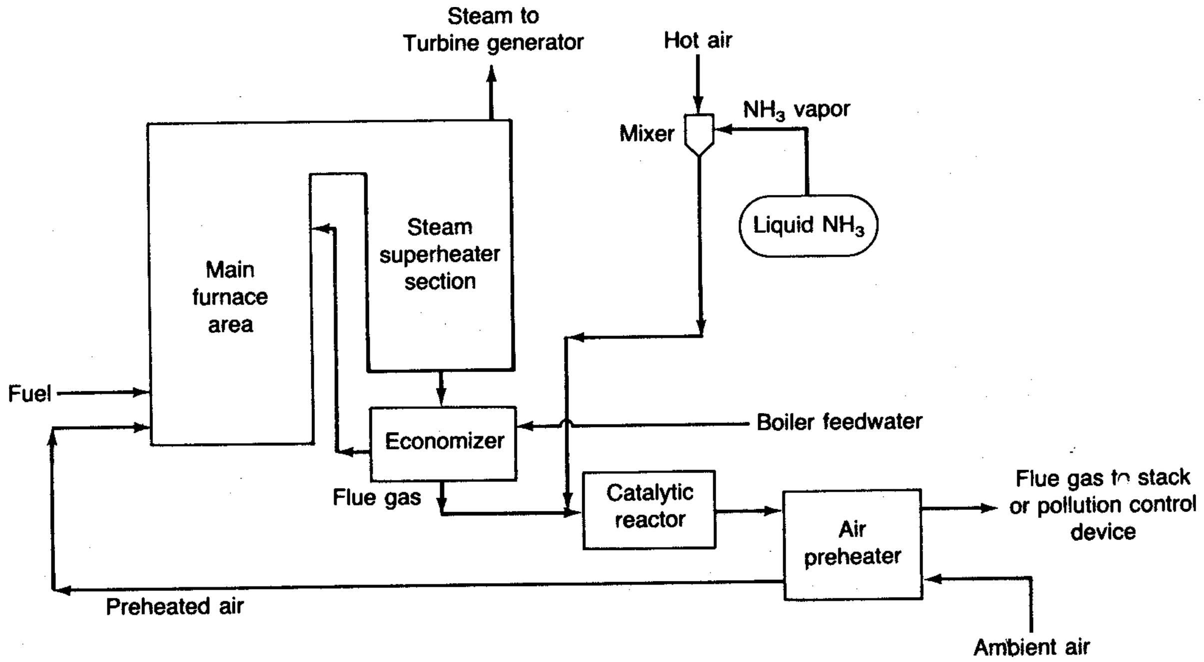

FIGURE 12.4-2. SCHEMATIC FLOW DIAGRAM FOR THE SELECTIVE CATALYTIC REDUCTION METHOD OF NO_X CONTROL (AWMA, 1992)

4.1.4 WHAT CATALYSTS ARE USED IN SELECTIVE CATALYTIC REDUCTION?

Catalyst formulation is the key to SCR system performance. The catalyst must reduce NO_x emissions without producing other pollutants or compounds that could damage the equipment downstream. The formulations of the catalytically active phases are proprietary, but generally fall into 3 categories of composition:

- Base metal catalysts which typically contain titanium and vanadium oxides and may also contain molybdenum, tungsten, and other elements. Base metal catalysts are used at temperatures between 450 and 800°F.

- Zeolite catalysts (crystalline aluminosilicate compounds) are used at high temperature operations, between 675 and 1100°F.

- Precious metal catalysts which contain metals such as platinum and palladium. These are used in clean, low temperature (between 350 and 550°F) operations.

Additional compounds may be present to give thermal or structural stability or to increase surface area. Catalyst beds may be constructed in a honeycomb, plate, or bed configuration.

4.1.5 WHAT ISSUES ARE OF CONCERN WHEN USING SELECTIVE CATALYTIC REDUCTION?

Catalyst deactivation and residual ammonia (ammonia slip) in the flue gas are two key considerations in SCR systems. Catalyst activity decreases with operating time due to fouling.

"Ammonia slip" is the unreacted ammonia that remains in the flue gas stream downstream of the SCR. Ammonia slip occurs when there is not enough NO_x in the flue gas to react with the injected ammonia. Ammonia slip is an indication that the ammonia injection rate should be reduced. As flue gas temperatures decrease, this excess ammonia can react with sulfur compounds from the fuel (especially SO_3) to form ammonium salts such as ammonium sulfate and ammonium bisulfate. Ammonium sulfate is a fine particulate and contributes to plume opacity. An increase in plume opacity can cause a facility to be out of compliance with state and/or federal opacity limits. Ammonium bisulfate is highly acidic and sticky and can result in fouling and corrosion when deposited downstream. Ammonia uptake by flyash can make disposal or reuse of the ash more of a challenge.

Ammonia slip is controlled by careful injection of the ammonia or urea into regions of the combustion unit with appropriate conditions (temperature, residence time, concentration) for the reduction reaction to occur. Distribution of the ammonia that matches flue gas strata is the important factor in control of ammonia slip. The amount of ammonia slip is usually monitored and used to determine the ammonia injection rate. Many units operate with an ammonia slip of less than 1 parts per million (ppm). Units are usually guaranteed to operate at less than 5 ppm.

4.1.6 WHAT WASTES RESULT FROM USING SELECTIVE CATALYTIC REDUCTION?

Other than the spent catalyst, SCR produces no waste. Spent catalyst is typically reactivated for use as a reducing agent or the components are recycled for other uses. When disposal is necessary, spent catalyst can be disposed of in approved landfills because EPA has determined that spent catalyst is not a hazardous waste (ICAC, 1997).

4.2 SELECTIVE NONCATALYTIC REDUCTION (SNCR)

4.2.1 WHAT POLLUTANTS ARE CONTROLLED USING SELECTIVE NONCATALYTIC REDUCTION?

NO_x is controlled using SNCR. This air pollution control technique is sometimes referred to as ammonia injection, even though most systems currently use urea injection.

4.2.2 HOW DOES SELECTIVE NONCATALYTIC REDUCTION WORK?

A reducing agent is injected into the NO_x-laden flue gas stream in a specific temperature zone in the upper combustion unit. The SNCR process requires proper mixing of the gas and the reagent, and the mixture must have adequate residence time for the reduction reactions to occur. High temperatures (between 1400 to 2000°F) are required to provide activation energy sufficient to eliminate the need for the use of catalysts. The NO_x is reduced to molecular nitrogen and water.

Note: SNCR is "selective" in that the reagent reacts primarily with NO_x, not with O_2 or other major components of the flue gas. Also, SNCR differs from SCR in that no catalyst is used in the former.

Five factors influence the performance of urea- or ammonia-based SNCR systems:

- Flue gas temperature;
- Reagent-to-NO_x ratio;
- NO_X concentration in the flue gas entering the combustion unit;
- Residence time; and
- Mixing.

4.2.3 WHAT REDUCING AGENTS ARE USED IN SELECTIVE NONCATALYTIC REDUCTION?

Ammonia or urea, with urea used most often. Ammonia is usually injected into the gas stream in the gaseous state; urea is injected in the aqueous state and therefore requires a longer residence time to volatilize.

The chemical reaction for the ammonia-based process is:

$$4NO + 4NH_3 + O_2 \rightarrow 4N_2 + 6H_2O \qquad (12.4\text{-}3)$$

The chemical reaction for the urea-based process is:

$$2NO + (NH_2)_2CO + \tfrac{1}{2}O_2 \rightarrow 2N_2 + 2H_2O + CO_2 \qquad (12.4\text{-}4)$$

4.2.4 WHAT ISSUES ARE OF CONCERN WHEN USING SELECTIVE NONCATALYTIC REDUCTION?

Excess urea degrades to nitrogen, carbon dioxide, and unreacted ammonia. Also, as with SCR, “ammonia slip” can occur with SNCR. To minimize ammonia slip, the SNCR must be designed to ensure good distribution and mixing of injected ammonia or urea within the proper temperature zone. Many units operate with an ammonia slip of less than 1 ppm. Units are usually guaranteed to operate at less than 5 ppm.

4.2.5 WHAT WASTES RESULT FROM USING SELECTIVE NONCATALYTIC REDUCTION?

No solid or liquid wastes are generated in the SNCR process, other than ammonia slip.

4.3 LOW NO_X BURNERS (LNB)

4.3.1 WHAT POLLUTANTS ARE CONTROLLED USING LOW NO_X BURNERS?

Low NO_x burners are used to inhibit the formation of NO_x.

4.3.2 HOW DO LOW NO_X BURNERS WORK?

Low-NO_x burners inhibit NO_x formation by controlling the mixing of fuel and air. Different burner manufacturers use different hardware to control the fuel-air mixing, but all designs essentially automate two methods of NO_x reduction: low excess air, described in Section 4.8, and staged overfire air, described in Section 4.9.

Low NO_x burners reduce:

- The oxygen level in the primary combustion zone to limit fuel NO_x formation;
- The flame temperature to limit thermal NO_x formation; and/or
- The residence time at peak temperature to limit thermal NO_x formation.

The most common design approach is to control NO_x formation by carrying out the combustion in stages:

- Staged air burners, or delayed combustion LNBs, are two-stage combustion burners which are fired fuel-rich in the first stage. They are designed to reduce flame turbulence, delay fuel/air mixing, and establish fuel-rich zones for initial combustion. The reduced availability of oxygen in the primary combustion zone inhibits fuel NO_x formation. Radiation of heat from the primary combustion zone results in reduced temperature. The longer, less intense flames resulting from the staged combustion lower flame temperatures and reduce thermal NO_x formation.

- Staged fuel burners also use two-stage combustion, but mix a portion of the fuel and all of the air in the primary combustion zone. The high level of excess air greatly lowers the peak flame temperature achieved in the primary combustion zone, reducing thermal NO_x formation. The secondary fuel is injected at high pressure into the combustion zone through a series of nozzles which are positioned around the perimeter of the burner. Because of its high velocity, the fuel gas entrains furnace gases and promotes rapid mixing with first stage combustion products. The entrained gases stimulate flue gas recirculation. Heat is transferred from the first stage combustion products prior to the second stage combustion and, as a result, second stage combustion is achieved with lower concentrations of oxygen and lower temperatures than would normally be encountered.

4.3.3 WHAT ISSUES ARE OF CONCERN WHEN USING LOW NO_X BURNERS?

LNBs are applicable to tangential and wall-fired boilers of various sizes but are not applicable to other boiler types such as cyclone furnaces or stokers. For example, in cyclone furnaces, combustion occurs outside of the main furnace. As a result, low NO_x burner modification of the furnace is not suitable for this combustion system design.

More specifically, staged air burners lengthen the flame configuration. As a result, staged air burners are applicable only to installations large enough to avoid impingement on the furnace walls. Staged fuel burners are designed only for gas firing.

4.3.4 WHAT WASTES RESULT FROM USING LOW NO_X BURNERS?

In some cases, LNBs with coal combustion increase the levels of carbon-in-ash. This can result in the ash requiring treatment as a waste, rather than being a marketable product.

4.4 NATURAL GAS BURNER/REBURN

4.4.1 WHAT POLLUTANTS ARE CONTROLLED USING NATURAL GAS BURNER/REBURN?

NO_x is controlled using natural gas burner/reburn. Also, as a secondary benefit, since it replaces 10 to 20 percent of the heat input from the primary fuel, sulfur dioxide emissions may be reduced, depending on the sulfur content of the primary fuel. When coal is the primary fuel, carbon dioxide, particulate and air toxics emissions are reduced.

4.4.2 HOW DOES NATURAL GAS BURNER/REBURN WORK?

In a reburn configured boiler, reburn fuel (natural gas, oil, or pulverized coal) is injected into the upper furnace region to convert the NO_x formed in the primary fuel's combustion zone to molecular nitrogen and water. Figure 12.4-3 is a schematic diagram of a typical reburn system. There are several natural gas burner/reburn boiler configurations. In general, the overall process occurs within three zones of the boiler:

- **Combustion zone**. The amount of fuel (coal, oil, or gas) input to the burners in the primary combustion zone is reduced by 10 to 20 percent. To minimize NO_x formation and to provide appropriate conditions for reburning, the burners or

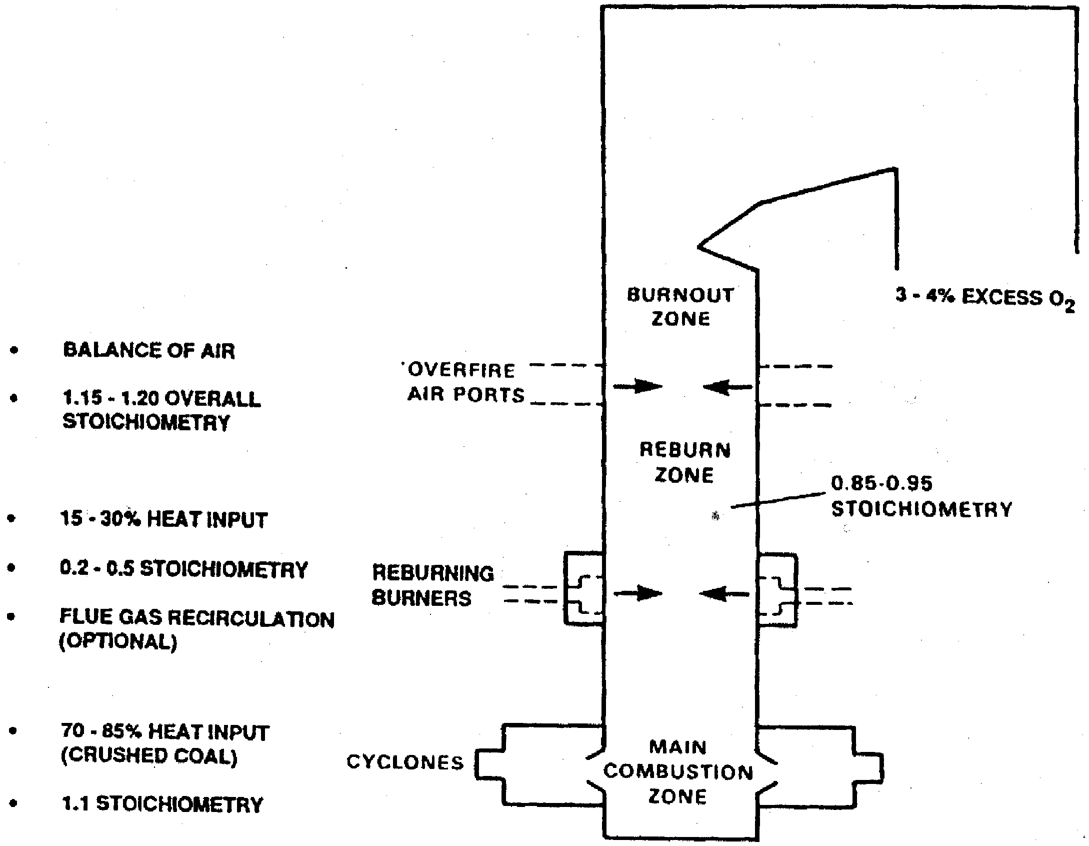

FIGURE 12.4-3. SCHEMATIC DIAGRAM OF A TYPICAL REBURN SYSTEM (AWMA, 1992)

cyclones may be operated at the lowest excess air consistent with normal commercial operation.

- **Gas reburning zone**. Reburn fuel (between 10 and 20 percent of boiler heat input) is injected above the primary combustion zone. This creates a fuel-rich region where hydrocarbon radicals react with NO_x to form molecular nitrogen. Recirculated flue gases may be mixed in with the reburn fuel before it is injected to promote better mixing within the boiler.

- **Burnout zone**. A separate overfire air system redirects air from the primary combustion zone to a location above the gas reburning reaction zone to ensure the complete combustion of any unreacted fuel and combustible gases. Separate overfire air systems also generally require new boiler penetrations and retrofitted ducting.

Operational parameters that affect the performance of reburn include:

- Reburn zone stoichiometry;
- Residence time in the reburn zone;
- Reburn fuel carrier gas; and
- Temperature and O_2 level in the burnout zone.

Decreasing the reburn zone stoichiometry can reduce NO_x emissions. However, decreasing the stoichiometry requires adding a larger portion of fuel to the reburn zone, which can adversely affect upper furnace conditions by increasing the furnace exit gas temperature.

4.4.3 WHAT ISSUES ARE OF CONCERN WHEN USING NATURAL GAS BURNER/REBURN?

There must be sufficient space in the furnace above the primary burners to allow installation of the necessary equipment.

4.4.4 WHAT WASTES RESULT FROM USING NATURAL GAS BURNER/REBURN?

None.

4.5 WATER/STEAM INJECTION

4.5.1 WHAT POLLUTANTS ARE CONTROLLED USING WATER/STEAM INJECTION?

NO_x from gas turbines are controlled using water/stream injection.

4.5.2 HOW DOES WATER /STEAM INJECTION WORK?

Water or steam is injected into the gas turbine, reducing the temperatures in the NO_x-forming regions. The water or steam can be injected into the fuel, the combustion air, or directly into the combustion chamber.

4.5.3 WHAT ISSUES ARE OF CONCERN WHEN USING WATER /STEAM INJECTION?

Both hydrocarbon and carbon monoxide emissions are increased by large rates of water injection.

Water injection can increase the rate of equipment corrosion. Although water injection usually results in a 2 to 3 percent decrease in efficiency, it may result in an increase in power output. With combustion turbines for example, the power increase results because fuel flow is increased to maintain turbine inlet temperature at manufacturers' specifications.

4.5.4 WHAT WASTES RESULT FROM USING WATER/STREAM INJECTION?

None.

4.6 STAGED COMBUSTION

4.6.1 WHAT POLLUTANTS ARE CONTROLLED USING STAGED COMBUSTION?

NO_x from gas turbines are controlled using staged combustion.

4.6.2 HOW DOES STAGED COMBUSTION WORK?

Most gas turbines were originally designed to operate with a stoichiometric mixture (an air-to-fuel ratio of 1.0). Several types of staging methods are used in order to reduce NO_x emissions from gas turbines. These include:

- Lean combustion;

- Lean premixed combustion; and
- Two-stage rich/lean combustion.

Lean Combustion

Lean combustion involves increasing the air-to-fuel ratio so that the peak and average temperature within the combustor will be less than that of the stoichiometric mixture. In lean combustion, the additional excess air cools the flame, which reduces the peak flame temperature and reduces the rate of thermal NO_x formation.

Lean Premixed Combustion

In a conventional combustor, air and fuel mixing and combustion take place simultaneously in the combustion zone. As a result, wide variations in air-to-fuel ratios exist, and the combustion of localized fuel-rich pockets produces significant levels of NO_x emissions. Lean premixed combustors, also known as two-stage lean/lean combustors, involve premixing of fuel and air at very lean air-to-fuel ratios prior to introduction into the combustion zone. Premixing results in a homogeneous mixture, which minimizes localized fuel-rich zones, resulting in greatly reduced NO_x formation rates.

Two-Stage Rich/Lean Combustion

Two-stage rich/lean combustors, also known as rich/quench/lean (RQL) combustors, burn fuel-rich in the primary zone and fuel-lean in the secondary zone. Incomplete combustion from the fuel-rich mixture in the primary zone produces lower temperatures (as compared to a stoichiometric mixture) and higher CO and hydrogen (H_2). The CO and H_2 replace some of the O_2 available for NO_x generation and also act as reducing agents for any NO_x formed in the primary zone. Thus, fuel nitrogen is released with minimal conversion to NO_x. The lower peak flame temperatures due to partial combustion also reduce the formation of thermal NO_x. Before entering the secondary zone, the combustion products of the primary zone pass through a low-residence-time quench zone where the combustion products are diluted by large amounts of air or water. This rapid dilution extinguishes the flames, cools the combustion products, and at the same time produces a lean mixture. The combustion of the lean mixture is then completed in the secondary zone under fuel lean conditions. This step minimally contributes to the formation of fuel NO_x because most of the fuel nitrogen will have been converted to N_2 prior to the lean combustion phase. Thermal NO_x is minimized during lean combustion due to the low flame temperature.

4.6.3 WHAT ISSUES ARE OF CONCERN WHEN USING STAGED COMBUSTION?

Lean Combustion

The performance of lean combustion is directly affected by the primary zone equivalence air-to-fuel ratio. The closer the ratio is to 1.0, the greater the NO_x emissions. However, if the ratio is reduced too far, CO emissions increase. This emissions tradeoff effectively limits the amount of NO_x reduction that can be achieved by lean combustion alone.

Lean Premixed Combustion

The primary factor affecting the performance of lean premixed combustors is the air-to-fuel ratio. To achieve low NO_x emissions levels, the air-to-fuel ratio must be maintained in a narrow range near the lean flammability limit of the mixture. Lean premixed combustors are designed to maintain this air-to-fuel ratio at the rated load. At reduced load conditions, the fuel input requirement decreases. To avoid combustion instability and excessive CO emissions that would occur as the air-to-fuel ratio reaches the lean flammability limit, all manufacturers' lean premixed combustors switch to diffusion-type combustion mode at reduced load conditions, which results in higher NO_x emissions.

Another factor that affects the performance of lean premixed combustors is the type of fuel used. Natural gas produces lower NO_x levels than do oil fuels, because natural gas has a lower flame temperature, and the ability to premix with air prior to delivery into the second combustion stage. When using liquid fuels, currently available lean premixed combustors require water injection to achieve appreciable NO_x reductions.

Two-Stage Rich/Lean Combustion

NO_x emissions from two-stage rich/lean combustors are affected primarily by the air-to-fuel ratio in the primary combustion zone, and by the quench air flow rate. If the air-to-fuel ratio is not selected carefully in the fuel-rich zone, both thermal and fuel NO_x formation can be increase. Further NO_x emissions can increase with reduced quench air flow rates, which in turn, increases the air-to-fuel ratio in the lean combustion stage.

4.6.4 WHAT WASTE RESULTS FROM USING STAGED COMBUSTION?

None.

4.7 FLUE GAS RECIRCULATION (FGR)

4.7.1 WHAT POLLUTANTS ARE CONTROLLED USING FLUE GAS RECIRCULATION?

Flue gas recirculation (FGR) is applied to reduce NO_x formation.

4.7.2 HOW DOES FLUE GAS RECIRCULATION WORK?

A portion of flue gas is recycled back to the primary combustion zone. This system reduces NO_x formation by two mechanisms:

- Heating in the primary combustion zone of the inert combustion products contained in the recycled flue gas lowers the peak flame temperature, thereby reducing thermal NO_x formation.
- To a lesser extent, FGR reduces thermal NO_x formation by lowering the oxygen concentration in the primary flame zone.

The recycled flue gas may be pre-mixed with the combustion air or injected directly into the flame zone. Direct injection allows more precise control of the amount and location of FGR.

Note: In order for FGR to reduce NO_x formation, recycled flue gas must enter the flame zone.

4.7.3 WHAT ISSUES ARE OF CONCERN WHEN USING FLUE GAS RECIRCULATION?

The use of FGR has several limitations. The decrease in flame temperature alters the distribution of heat and can lower fuel efficiency. Because FGR reduces only thermal NO_x, the technique is applied primarily to natural gas or distillate oil combustion.

Flue gas recirculation requires modifications to the ductwork of the combustion unit. Additional power is required to operate recirculation fans, making the operating cost of flue gas recirculation higher than some other combustion techniques.

4.7.4 WHAT WASTES RESULT FROM USING FLUE GAS RECIRCULATION?

None.

4.8 LOW EXCESS AIR (LEA)

4.8.1 WHAT POLLUTANTS ARE CONTROLLED USING LOW EXCESS AIR?

Low excess air is applied to reduce NO_x formation.

Excess air is the amount of air (oxygen) above the level stoichiometrically required for 100 percent combustion of the fuel. Because mixing of air and fuel is not complete at all times in all regions of the combustor, some excess air is required to ensure complete combustion of the fuel and to prevent CO and smoke formation or excess carbon-in-ash.

4.8.2 HOW DOES LOW EXCESS AIR WORK?

Low excess air works by reducing levels of excess air to the combustor, usually by adjustments to air registers and/or fuel injection positions, or through control of overfire air dampers. The lower oxygen concentration in the burner zone reduces conversion of the fuel nitrogen to NO_x. Also, under excess air conditions in the flame zone, a greater portion of fuel-bound nitrogen is converted to N_2 therefore reducing the formation of fuel NO_x.

4.8.3 WHAT ISSUES ARE OF CONCERN WHEN USING LOW EXCESS AIR?

Issues that can be associated with low excess air systems include:

- Too little excess air can result in increased emissions of carbon monoxide or unburned carbon smoke; and

- Too little excess air can reduce flame stability.

4.8.4 WHAT WASTES RESULT FROM USING LOW EXCESS AIR?

None.

4.9 STAGED OVERFIRE AIR

4.9.1 WHAT POLLUTANTS ARE CONTROLLED USING STAGED OVERFIRE AIR?

Staged overfire air is applied to reduce NO_x formation.

4.9.2 HOW DOES STAGED OVERFIRE AIR WORK?

Staged overfire air works by:

- Partially delaying and extending the combustion process. This results in less intense combustion and cooler flame temperatures, thereby suppressing thermal NO_x formation.

- Lowering the concentration of air in the burner combustion zone where volatile fuel nitrogen is evolved, thereby suppressing fuel NO_x formation.

Staged combustion, or off-stoichiometric combustion, combusts the fuel in two or more steps. A percentage of the total combustion air is diverted from the burners and injected through ports above the top burner level. The total amount of combustion air fed to the furnace remains unchanged. Initially, fuel is combusted in a primary, fuel-rich, combustion zone. Combustion is completed at lower temperatures in a secondary, fuel-lean, combustion zone. The sub-stoichiometric oxygen introduced with the primary combustion air into the high temperature, fuel-rich zone reduces fuel and thermal NO_x formation. Combustion in the secondary zone is conducted at a lower temperature, reducing thermal NO_x formation.

Staged overfire air combustion involves firing the burners more fuel-rich than normal while admitting the remaining combustion air through overfire air ports or an idle top row of burners.

4.9.3 WHAT ISSUES ARE OF CONCERN WHEN USING STAGED OVERFIRE AIR?

Staged overfire air systems provide less available oxygen in the primary combustion zone. This can result in:

- Increased emissions of CO, organic compounds, and visible emissions;

- Reduced flame stability, and changed furnace heat release rates and flue gas exit temperatures;

- Increased upper furnace ash deposits, referred to as “slagging”; and

- Increased corrosion due to a reducing atmosphere in the lower furnace.

4.9.4 WHAT WASTES RESULT FROM USING STAGED OVERFIRE AIR?

None.

4.10 NONSELECTIVE CATALYTIC REDUCTION (NSCR)

4.10.1 WHAT POLLUTANTS ARE CONTROLLED USING NONSELECTIVE CATALYTIC REDUCTION?

Primarily NO_x, but NSCR reduces CO and hydrocarbons (HC) as well.

4.10.2 HOW DOES NONSELECTIVE CATALYTIC REDUCTION WORK?

NSCR technique is essentially the same as the catalytic reduction systems that are used in automobiles applications. NSCR is achieved by placing a catalyst in the exhaust stream of the engine.

NSCR technique is also referred to as three-way catalyst because it simultaneously reduces NO_x, CO, and HC to water, CO_2, and N_2. This conversion occurs in two discrete and sequential steps:

$$\begin{array}{llllllll}
\text{Step 1:} & 2CO & + & O_2 & \rightarrow & 2CO_2 & & \\
 & 2H_2 & + & O_2 & \rightarrow & 2H_2O & & \\
 & HC & + & O_2 & \rightarrow & CO_2 & + & H_2O \\
 & & & & & & & \\
\text{Step 2:} & NO_x & + & CO & \rightarrow & CO_2 & + & N_2 \\
 & NO_x & + & H_2 & \rightarrow & H_2O & + & N_2 \\
 & NO_x & + & HC & \rightarrow & CO_2 & + & H_2O + N_2
\end{array}$$

In the first step, excess oxygen is removed from the exhaust gas. Because CO and HC react more readily with O_2, the O_2 content of the exhaust is kept below approximately 0.5 percent. This will ensure adequate NOx reduction in the second step. Therefore, NSCR is applicable only to carbureted rich-burn engines.

Typically, natural gas is used as the NO_x reducing agent in NSCR. Natural gas is injected into the exhaust stream ahead of the catalyst reactor and acts as a reducing agent for NO_x. Figure 12.4-4 is a schematic diagram of a typical NSCR system.

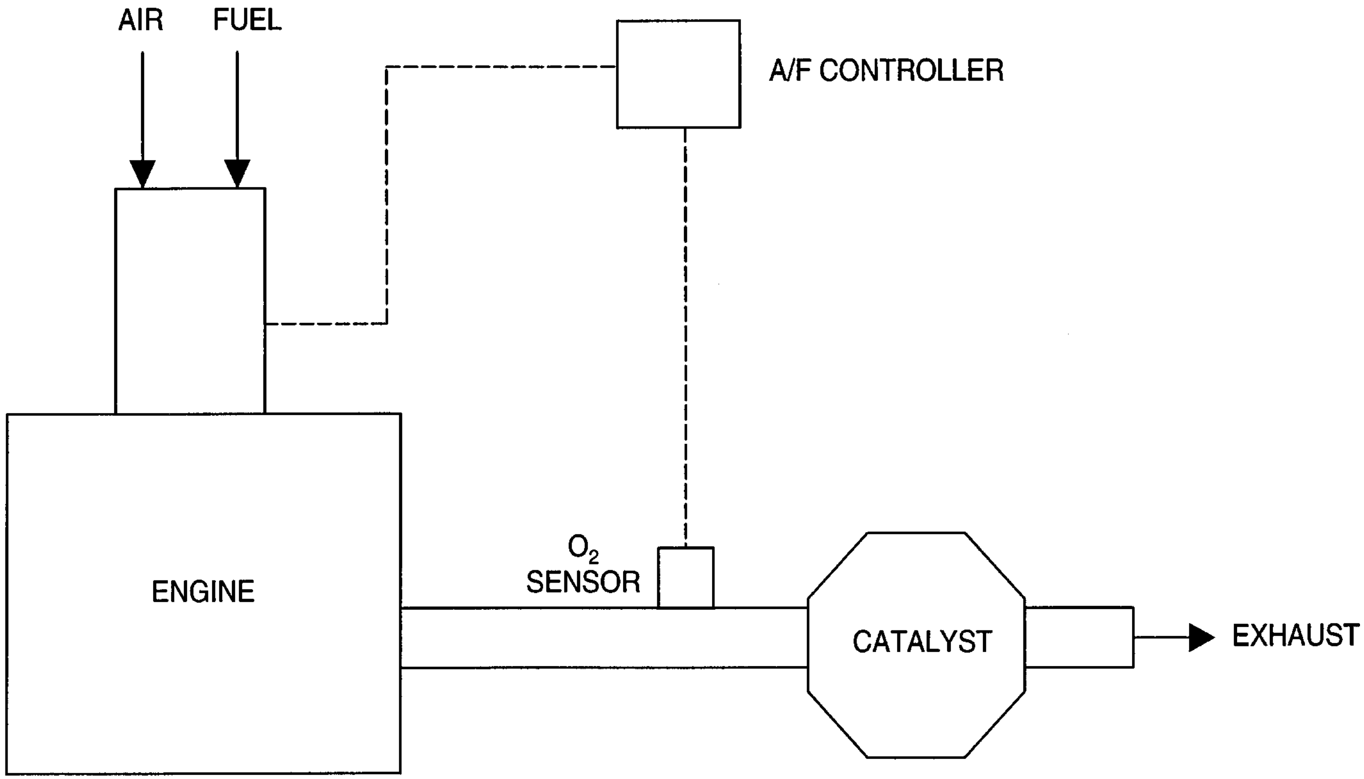

FIGURE 12.4-4. SCHEMATIC OF A NONSELECTIVE CATALYTIC REDUCTION SYSTEM DESIGN WITH A SINGLE CALALYTIC REACTOR

4.10.3 WHAT ISSUES ARE OF CONCERN WHEN USING NONSELECTIVE CATALYTIC REDUCTION?

The main issue of concern with NSCR is its limited applicability resulting from the narrow range of exhaust O_2 level required for consistent NO_x reduction. NSCR can be installed on new engines or retrofit to existing units. However, because of the air-to-fuel ratio necessary for the operation of NSCR, this control technique can be used on carbureted rich-burn engines, but not to fuel-injected units.

Other issues of concern when using NSCR include:

- Control of air-to-fuel ratio: In order to reduce NO_x emissions while minimizing CO emissions from the catalyst, the exhaust O_2 concentration must be maintained at approximately 0.5 percent by volume. This O_2 level is accomplished by maintaining the air-to-fuel ratio in a narrow band.

- Exhaust temperature: The operating temperature range for various NSCR catalysts is from 375° to 825° C (700° to 1500° F). For NO_x reductions of 90 percent r greater, the temperature range narrows to approximately 425° to 650° C (800° to 1200° F). Although this temperature range is based on a compilation of available catalyst formulations, individual catalysts will have narrower operating temperature range, and maximum reduction efficiencies may not be achievable over the entire spectrum of exhaust temperatures for an engine operating in a variable load application. Moreover, abnormal operating conditions, such as backfiring, can result in excessive temperatures that damage the highly porous catalyst surface, permanently reducing the emission reduction capability of the catalyst.

- Masking or poisoning of the catalyst: Masking occurs when materials deposit on the catalyst surface and cover the active areas. Poisoning occurs then materials deposit on the catalyst surface and chemically react with active areas. Masking and poisoning reduce the catalyst’s reduction capacity. Masking agents include sulfur, calcium, fine silica particles, and hydrocarbons. Poisoning agents include phosphorus, lead, and chlorides. Examples of masking and poisoning containing fuels include landfill and digester gas fuels.

4.10.4 WHAT WASTES RESULT FROM USING NONSELECTIVE CATALYTIC REDUCTION?

None.

4.11 WET ACID GAS SCRUBBERS

4.11.1 WHAT POLLUTANTS ARE CONTROLLED USING WET ACID GAS SCRUBBERS ?

Wet acid gas scrubbers are used to control SO_2 emissions.

4.11.2 HOW DO WET ACID GAS SCRUBBERS WORK?

In most large systems, a sorbent material is milled and mixed into a slurry and pumped to an absorber reaction tank. Flue gas is fed to the reactor and the SO_2 in the gas is absorbed, neutralized, and partially oxidized as the result of coming in contact with the sorbent material. Wet acid gas scrubbers occur downstream of the particulate control devices to avoid erosion of the desulfurization equipment and possible interference of particulate matter with the scrubbing process. The slurry falls to a perforated plate tray where additional SO_2 is absorbed into the froth created by the interaction of the flue gas and the slurry on the tray. The slurry then drains back into the reaction tank. A fraction of the slurry is continuously diverted to the disposal (dewatering) system. Refer to Figure 12.4-5.

4.11.3 WHAT SORBENT MATERIAL IS USED IN WET ACID GAS SCRUBBERS?

Lime or limestone is used as the sorbent material. Both processes are nonregenerable; the reagent is consumed by the process and must be continually replaced. Lime scrubbing and limestone scrubbing are very similar in equipment and process flow, except that lime is a much more reactive reagent than limestone. The major advantage of limestone scrubbing is that the absorbent material is abundant and inexpensive. The disadvantages include scaling (hard plugging), equipment plugging (soft plugging), and corrosion. The advantages of lime scrubbing include better utilization of the reagent and more flexibility in operations. The major disadvantage is the high cost of lime relative to limestone.

4.11.4 WHAT ISSUES ARE OF CONCERN WHEN USING WET ACID GAS SCRUBBERS?

Several parameters must be controlled in a wet scrubber to ensure continuous operation. The pH of the slurry is one of these. Early scrubbers suffered from severe scale and plugging problems. Scaling (hard plugging) resulted from precipitation of limestone in piping and on other surfaces if the pH was too high. A low pH indicates a high concentration of calcium sulfite in the slurry and can cause plugging (soft plugging) in pipes and other passages. The final reaction product, calcium sulfate, can also produce hard plugging if it precipitates due to changes in pH.

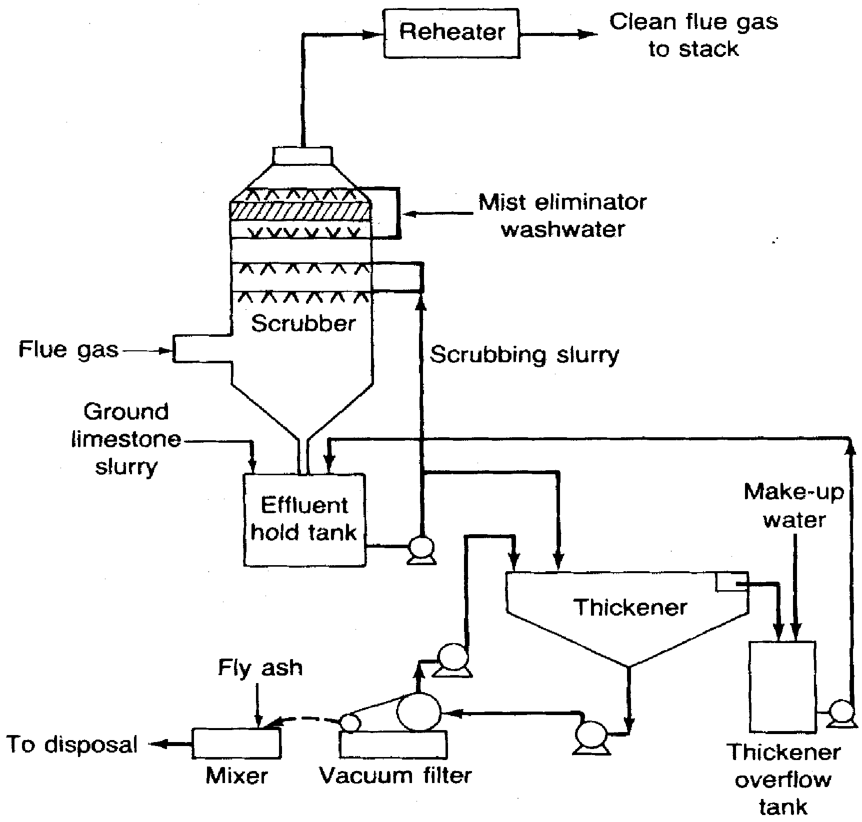

FIGURE 12.4-5. SCHEMATIC PROCESS FLOW DIAGRAM FOR A LIMESTONE-BASED SO_2 WET SCRUBBING SYSTEM (COOPER AND ALLEY, 1994)

Fresh lime or limestone slurry is introduced into the system to control pH in the scrubber slurry. Since the volume of slurry in the scrubber vessel must remain relatively constant, a bleed stream of slurry must also be withdrawn from the scrubber.

Stainless steel, commonly 317L or similar quality, in wet acid gas scrubbers must be protected from corrosion due to high concentrations of chloride salts in the slurry which is normally limited to a fixed value. These salts are controlled by replacement of liquid of the slurry. The combination of slurry necessary to control pH and concentration of limestone in the fresh slurry are both varied to satisfy both of these limitations.

These operational factors affect SO_2 removal. Other operational parameters, such as the recirculation rate of the slurry and the spray atomization characteristics in the scrubber will also affect acid gas removal performance.

4.11.5 WHAT WASTES RESULT FROM USING WET ACID GAS SCRUBBERS ?

Wet acid gas scrubbers generate large quantities of spent slurry. This waste can be disposed of by:

- Ponding the spent slurry without dewatering. This is the simplest method, but requires a large ponding area and the management of the site is expensive.
- A combination of dewatering, secondary dewatering, and landfilling. This is the most common disposal strategy in the United States.
- Sulfite sludge can be mixed with flyash and lime to yield a material suitable for landfilling.
- Gypsum can be concentrated to a cake and sold for use in wallboard or fertilizer manufacture.

4.12 SPRAY DRYER ABSORBERS (SDA)

4.12.1 WHAT POLLUTANTS ARE CONTROLLED USING SPRAY DRYER ABSORBERS?

Spray dryer absorbers (SDA) are used primarily to control SO_2. SDA have been applied to utility boilers, smaller industrial applications, and for combined hydrogen chloride (HCl) and SO_2 control at waste-to-energy units.

Spray dryer absorbers are also referred to as spray dryers, spray absorbers, dry scrubbers, and semi-wet scrubbers.

4.12.2 HOW DO SPRAY DRYER ABSORBERS WORK?

Unlike a wet scrubber, an SDA is positioned before the particulate matter collector. In an SDA, a highly atomized or aqueous lime slurry is sprayed into an absorption tower so that the slurry droplets dry as they contact the hot flue gas. Sulfur dioxide is absorbed by the slurry, forming $CaSO_3/CaSO_4$. The liquid-to-gas ratio is such that the water evaporates before the droplets reach the bottom of the tower. The dry solids are carried out with the gas and collected in a fabric filter with the fly ash. Refer to Figure 12.4-6.

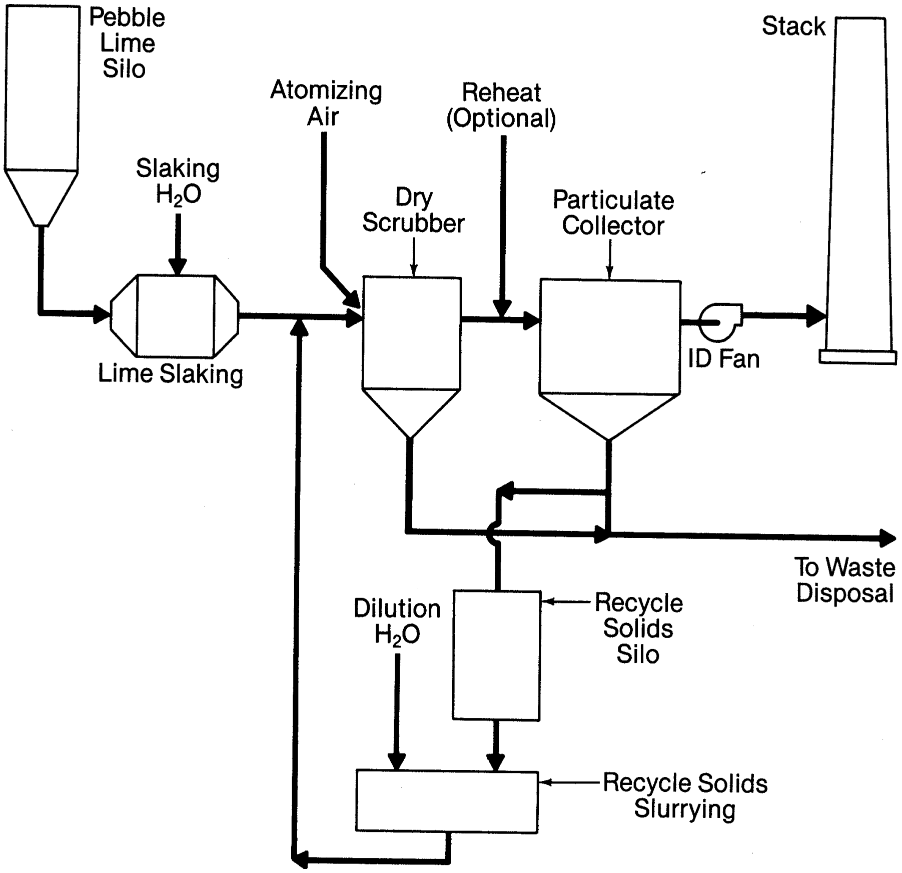

FIGURE 12.4-6. SPRAY DRYER ABSORBER SYSTEM SCHEMATIC (BABCOCK & WILCOX, 1992)

4.12.3 WHAT SORBENT MATERIAL IS USED IN SPRAY DRYER ABSORBERS?

Slaked lime is usually used as the sorbent.

4.12.4 WHAT ISSUES ARE OF CONCERN WHEN USING SPRAY DRYER ABSORBERS?

The reagent slurry feed into the spray dryer generally is a mix of two feed systems and these systems require close monitoring and maintenance to ensure proper operation of the SDA. The first feed system is the rich lime slurry. The slurry is usually produced by slaking quick lime (CaO) at the plant site to produce hydrated lime ($Ca(OH)_2$) in a water based slurry. High quality water is necessary for the slaking operation. The second feed is “dilution” water, which can contain plant wastewater, river water, and landfill leachate.

Both of these feeds are used to control operation of the SDA. Acid gas removal is achieved by regulating the rich lime slurry feed rate. The longer the slurry droplets take to dry, while maintaining a liquid surface, the greater the chemical reactivity of the lime and resulting removal of acid gases. This is accomplished by regulating the dilution water feed rate to control the SDA outlet gas to a fixed temperature as low as possible while maintaining the temperature high enough to ensure the drying of solids to protect ductwork and downstream particulate control devices.

Controls for both feeds are linked because the slurry contains water and will also affect the outlet gas temperature. Most systems measure the acid gas concentration and temperature in the outlet gas of the SDA, and the feed rates are regulated based on these measurements.

Control problems may occur if the system can not feed enough rich lime slurry into the unit. This can result from improper design of the dual feed control system or if the rich lime slurry is not sufficiently reactive to produce proper acid gas control alone.

Another concern is the response time of the feed system to varying acid gas concentrations in the flue gas stream. Some facilities mix both feeds in a tank prior to SDA injection. Acid gas concentrations will vary with time. This will occur quickly for some processes and will be more pronounced in smaller units. Therefore, the mix tank must be designed to change its lime concentration quickly enough to respond to changes in acid gas concentration.

4.12.5 WHAT WASTES RESULT FROM USING SPRAY DRYER ABSORBERS?

Spray dryer absorbers generate dry particulate matter that is collected in downstream air pollution control devices.

4.13 DRY INJECTION

4.13.1 WHAT POLLUTANTS ARE CONTROLLED USING DRY INJECTION?

Acid gas pollutants including SO_2 and HCl are controlled using dry injection.

4.13.2 HOW DOES DRY INJECTION WORK?

Dry injection, often referred to as dry sorbent injection (DSI), involves the addition of a dry reagent to the gas stream to react with acid gases present. The reagent may be injected into the combustion zone or into the downstream duct. The reaction products are collected in a particulate collection device. In some cases, a portion of the collected reaction products is reinjected to increase acid gas removal and decrease reagent consumption.

4.13.3 WHAT SORBENT MATERIAL IS USED IN DRY INJECTION?

Hydrated lime [$Ca(OH)_2$] or soda ash [$Na_2(CO_3)$] is usually used as the sorbent material.

4.13.4 WHAT ISSUES ARE OF CONCERN WHEN USING DRY INJECTION?

The main issue of concern is determining the proper reagent feed rate appropriate for the level of acid gas in the flue gas stream and making prompt changes, when necessary, in the feed rate to compensate for changes in the acid gas flow rate.

4.13.5 WHAT WASTES RESULT FROM USING DRY INJECTION?

Dry injection generates dry particulate matter that is collected in a downstream particulate collection device, usually a fabric filter.

4.14 CARBON ADSORPTION

4.14.1 WHAT POLLUTANTS ARE CONTROLLED USING CARBON ADSORPTION?

Carbon adsorption is applied to control emissions of gaseous pollutants, primarily organic compounds. Carbon adsorption is commonly used to control VOC emissions from dry cleaners, degreasing operations, publication gravure printing plants, chemical processing industry, petroleum industry, and landfills. Carbon systems have also been developed for the adsorption of sulfur oxides.

In contrast to incineration techniques that destroy the organic compounds, carbon adsorption provides a favorable control option when the organic compounds in the emission stream are valuable because recovery of the organics may be possible.

4.14.2 HOW DOES CARBON ADSORPTION WORK?

Adsorption is the concentration of a substance **on the surface** of a liquid or solid. The adsorbed substance does not penetrate within the crystal lattice of the solid or dissolve within it, but remains entirely on the surface. Adsorption is **not** the same as absorption, in which the substance **passes through the surface** to become distributed throughout the phase.

Carbon adsorption air pollution control techniques are based on the principle that if the intermolecular forces between the adsorbent and the pollutant are greater than those existing between the molecules of the pollutant, the pollutant will condense on the surface of the adsorbent. The adsorptive capacity of the carbon bed tends to increase with the concentration, molecular weight, diffusity, and boiling point of the gas phase organics and decrease with increased temperature of the flue gas.

To allow gas vent streams containing organic compounds to come into contact with the activated carbon, the carbon granules are usually arranged in either a vertical or horizontal vessel. Small units are manufactured with the carbon in place (canisters). Larger units are constructed so that the carbon granules are loaded after installation; two configurations are common:

- **Fixed-bed systems** are non-moving beds of activated carbon that are alternately placed on-line and regenerated. When a continuous emission stream is being treated, at least one bed is on line and one bed is on stand-by or being regenerated at any given time. When the first bed approaches its capacity, the emission stream is redirected to the second bed and the first bed is regenerated.

- **Fluidized-bed systems** contain one or more beds of loose, beaded activated carbon. The emission stream is directed upward through the bed and the organic compounds are adsorbed onto the carbon. The flow of the emission stream stirs the carbon beads, causing them to fluidize and flow through the adsorber. Fresh carbon beads are continuously metered into the bed and organic compounds-laden carbon is removed for regeneration.

Because the amount of organics that can be adsorbed per unit mass of activated carbon increases as the temperature decreases, the flue gas is often passed through a cooler before entering the adsorbent bed. The cooled gas stream travels through the adsorbent bed where the organic compounds are removed and the remaining flue gas vented or returned to the source process. When the capacity limit of the adsorbent is reached, the carbon granules can be removed and replaced (canister systems), regenerated in place, or removed for regeneration. The saturated carbon bed is regenerated by direct contact with low pressure steam.

Carbon adsorption is sensitive to emission stream conditions. The presence of liquid or solid particles, high boiling organics, or polymerized substances may require pretreatment procedures such as filtration.

4.14.3 WHAT SORBENT MATERIAL IS USED IN CARBON ADSORPTION?

Activated carbon is the preferred adsorbent material to remove organic compounds from gas streams. It is produced by heating wood charcoal to between 350 and 1000°C in a vacuum, or in air, steam, or other gases. The activation process distills hydrocarbon impurities from the charcoal and exposes a larger free surface for possible adsorption. Activated carbon has a high affinity for:

- Nonpolar compounds;
- High-molecular-weight materials; and
- Compounds with low volatility.

4.14.4 WHAT ISSUES ARE OF CONCERN WHEN USING CARBON ADSORPTION?

One issue with the carbon adsorption technique is that the capacity of the adsorbent bed for adsorbing organic compounds progressively deteriorates with use.

4.14.5 WHAT WASTES RESULT FROM USING CARBON ADSORPTION?

Activated carbon beds are usually regenerated with steam. The steam is condensed and the condensate, along with the recovered hydrocarbons, are sent to a wastewater treatment facility.

4.15 THERMAL OXIDATION

4.15.1 WHAT POLLUTANTS ARE CONTROLLED USING THERMAL OXIDATION?

Thermal oxidation is applied as a post-process technique to control emissions of gaseous pollutants, primarily CO and VOC. Given a high enough temperature and a long enough residence time, combustion can oxidize virtually all hydrocarbons to carbon dioxide and water.

Thermal oxidizers, also known as thermal incinerators, or afterburners, are used for low concentrations of organic compounds. The concentration of the VOC in the flue gas or the concentration of organics in the air must be kept substantially lower than the lower explosive limit.

4.15.2 HOW DOES THERMAL OXIDATION WORK?

Flue gas, air, and fuel (typically natural gas) are continuously delivered to the reactor, where the fuel and air are combusted in the firing unit. The energy released by combustion of the fuel heats the flue gas which passes through the reactor where the organic pollutants are reacted (oxidized) to harmless endproducts. The oxidation reactions require an elevated temperature (1200 -

2000°F) and a residence time of 0.2 to 2.0 seconds. Figure 12.4-7 shows a typical thermal oxidizer.

4.15.3 WHAT ISSUES ARE OF CONCERN WHEN USING THERMAL OXIDATION?

Issues that can be associated with thermal oxidation systems include:

- Thermal oxidation is not well suited to gas streams with highly variable flow rates because the reduced residence time, and poor mixing decrease the completeness of the combustion during increased flow rates. This causes the combustion chamber temperature to fall, decreasing the destruction efficiency.

- Combustion of organic gases represents an explosion hazard.

- Thermal oxidizers that are not operating efficiently can produce air pollutants. The incomplete combustion of many organic compounds can result in the formation of aldehydes and organic acids.

- If the heat from the fuel burned is not recovered for process needs, or some useful purpose, it amounts to wasted energy. This also results in extra releases of CO_2, a greenhouse gas.

4.15.4 WHAT WASTES RESULT FROM USING THERMAL OXIDATION?

None.

4.16 CATALYTIC OXIDATION

4.16.1 WHAT POLLUTANTS ARE CONTROLLED USING CATALYTIC OXIDATION?

Catalytic oxidation is applied primarily to control CO and gaseous organic compounds, including organic HAPs. CO oxidation catalysts are typically used on gas turbines that use steam injection which can increase CO and unburned hydrocarbons in the exhaust.

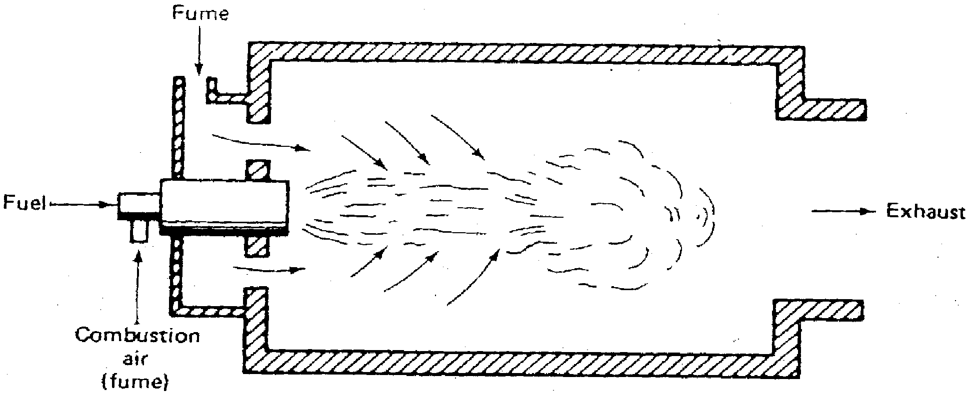

FIGURE 12.4-7. SCHEMATIC OF A THERMAL OXIDIZER (AWMA, 1992)

4.16.2 HOW DOES CATALYTIC OXIDATION WORK?

Catalytic oxidation is very similar to thermal oxidation. In catalytic oxidation the gases pass over a catalyst bed that promotes oxidation at a lower temperature (650 - 800°F) than required for thermal oxidation.

Catalytic oxidation is not applied as widely as thermal oxidation because catalytic oxidation is more sensitive to pollutant characteristics and process conditions than thermal oxidation. Figure 12.4-8 shows a typical catalytic oxidizer.

4.16.3 WHAT CATALYST MATERIAL IS USED IN CATALYTIC OXIDATION?

Catalysts include:

- Metals in the platinum family; and
- Oxides of copper, chromium, vanadium, nickel, and cobalt.

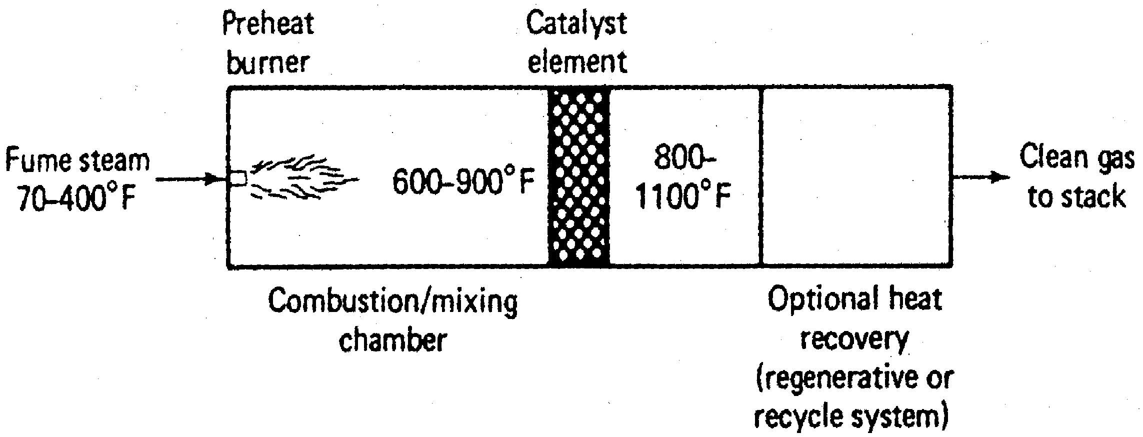

FIGURE 12.4-8. SCHEMATIC OF CATALYTIC OXIDIZER (AWMA, 1992)

4.16.4 WHAT ISSUES ARE OF CONCERN WHEN USING CATALYTIC OXIDATION?

Issues that can be associated with catalytic oxidation systems include:

- Catalysts are subject to poisoning by many elements that are present in industrial emissions, particularly halogens, sulfur compounds, zinc, arsenic, lead, mercury, and particulates;
- High temperatures can decrease catalyst activity;
- Combustion of organic gases represents an explosion hazard; and
- Catalytic oxidizers that are not operating efficiently can produce air pollutants. The incomplete oxidation of many organic compounds can result in the formation of aldehydes and organic acids that may create additional air pollution problems.

4.16.5 WHAT WASTES RESULT FROM USING CATALYTIC OXIDATION?

Spent catalyst should be considered as a potential hazardous pollutant in the solid waste stream.

4.17 FLARES

4.17.1 WHAT POLLUTANTS ARE CONTROLLED USING FLARES?

Flares are used to control CO and most gaseous organic compounds. Flares are most commonly used for disposal of large quantities of unwanted flammable gases and vapors resulting from process upsets and emergencies. Flares are used when the concentration of organics in the air equals or exceeds the lower explosive limit level or when the heating value of the emission stream cannot be recovered economically because of uncertain or intermittent flows. Flares are primarily used in the petroleum and petrochemical industries.

4.17.2 HOW DO FLARES WORK?

Vent gas containing organics is fed to and discharged from a stack. Mixing and combustion of the vent gas, air, and fuel take place above the stack exit in the atmosphere. Complete combustion must occur instantaneously because there is no residence chamber. Flare combustion efficiency is related to flame temperature, residence time of gases in the combustion zone, the amount of oxygen available for combustion, and degree of flue gas/oxygen mixing.
Figure 12.4-9 shows a typical flare.

Flare configurations can be classified as:

- **Smokeless** flares introduce steam or air to ensure the efficient gas/air mixing and turbulence necessary for complete combustion. Smokeless flaring is required for the destruction of organic compounds heavier than methane. Steam-assisted smokeless flares are most common.

- **Nonsmokeless** flares are used to destroy organic vapor streams that burn readily and do not produce smoke.

- **Fired, or endothermic**, flares require additional energy to ensure complete oxidation of the waste streams such as sulfur and ammonia.

4.17.3 WHAT ISSUES ARE OF CONCERN WHEN USING FLARES?

Issues that can be associated with flares include:

- Combustion of organic gases represents an explosion hazard.

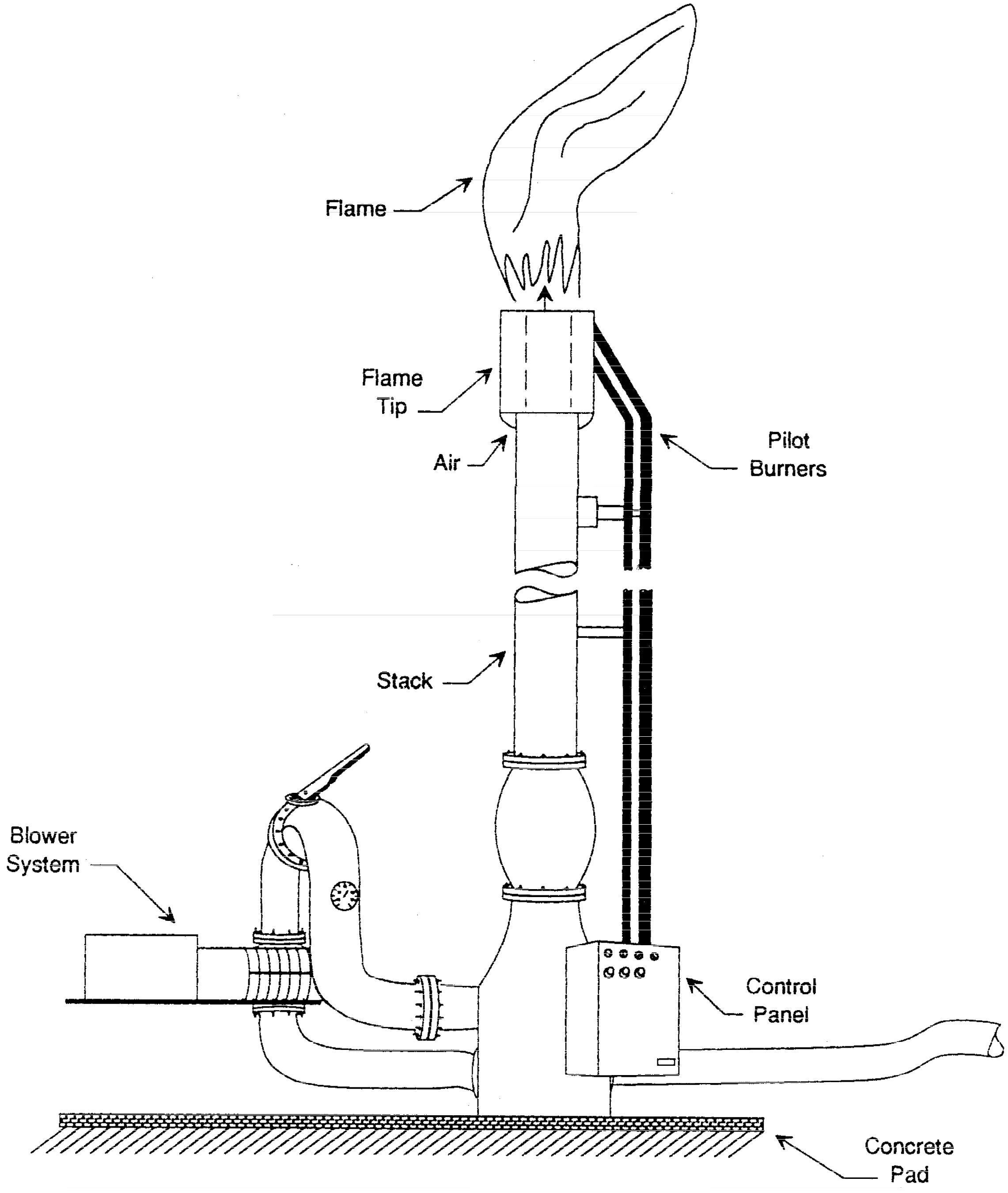

FIGURE 12.4-9. TYPICAL OPEN FLARE (AWMA, 1992)

- Flares that are not operating efficiently can produce air pollutants.

- When a flare is not operating properly, incomplete combustion can occur. The incomplete combustion of many organic compounds can result in the formation of aldehydes and organic acids that may create additional air pollution problems.

4.17.4 WHAT WASTES RESULT FROM USING FLARES?

None.

4.18 FLOATING ROOF SYSTEMS

4.18.1 WHAT POLLUTANTS ARE CONTROLLED USING FLOATING ROOF TANK SYSTEMS?

Floating roof tank systems are used by petroleum producing and refining, petrochemical and chemical manufacturing, bulk storage and transfer operations, and other industries consuming or producing organic liquids to reduce the air emissions of VOC that occur as the result of evaporation.

4.18.2 HOW DO FLOATING ROOF TANK SYSTEMS WORK?

Three designs are used to reduce evaporative loss of liquids and vapors during the storage of organic liquids

- **External floating roof tanks** (EFRT) have an open-topped cylindrical steel shell with a roof that floats on the surface of the stored liquid. The roof rises and falls with the liquid level in the tank. The floating roof consists of a deck, fittings, and a rim seal. The rim seal system is attached to the deck perimeter and contacts the tank wall. The seal system slides against the tank wall as the roof is raised and lowered. The external floating roof design limits evaporative loss of the stored liquid to losses from the rim seal system and deck fittings (standing storage loss) and any exposed liquid on the tank walls (withdrawal loss).

- **Internal floating roof tanks** (IFRT) have both a fixed permanent roof and a floating roof inside. The function of the fixed roof is not to act as a vapor barrier, but to block the wind. The deck in internal floating roof tanks rises and falls with the liquid level and either floats directly on the liquid surface (contact deck) or rests on pontoons several inches above the water (noncontact deck). Noncontact decks are the most common type currently in use. Both contact and noncontact decks incorporate rim seals and deck fittings to reduce evaporative loss of the stored liquid. These tanks are freely vented by circulation vents at the top of the fixed roof. The vents minimize the possibility of organic vapors accumulating in the tank vapor space to concentration levels that approach the explosive range.

- **Domed External Floating Roof Tanks** are usually the result of the retrofit of an EFRT. These tanks have the same type of deck, deck fittings, and rim seals used in EFRT as well as a fixed roof at the top of the shell like IFRT. Like the IFRT, these tanks are freely vented by circulation vents at the top of the fixed roof.

4.18.3 WHAT ISSUES ARE OF CONCERN WHEN USING FLOATING ROOF TANK SYSTEMS?

Deterioration of seals; inspection and maintenance are important for continued good service.

4.18.4 WHAT WASTES RESULT FROM USING FLOATING ROOF TANK SYSTEMS?

None.

4.19 MECHANICAL COLLECTORS

4.19.1 WHAT POLLUTANTS ARE CONTROLLED USING MECHANICAL COLLECTORS?

Coarse and medium particulate matter are controlled using mechanical collectors.

4.19.2 HOW DO MECHANICAL COLLECTORS WORK?

The five major types of mechanical collectors are settling chambers, elutriators, momentum separators, centrifugal collectors, and cyclones. These devices are discussed below.

Settling Chambers

The simplest mechanical collectors are settling chambers, which rely on gravitational settling as a collection mechanism. Settling chambers prevent excessive abrasion and dust loading in primary collection devices by removing large particles from the gas stream.

There are two primary types of settling chambers: the expansion chamber and the multiple-tray chamber. In an expansion chamber, the velocity of the gas stream is significantly reduced as the gas expands into a large chamber. The reduction in velocity allows larger particles to settle out of the gas stream. A multiple-tray settling chamber is an expansion chamber with a number of thin trays closely spaced within the chamber, which causes the gas stream to flow horizontally between them. An expansion chamber must be very large to collect any small particles, but multiple-tray chambers have lower volume requirements for collection of small particles (greater than, or equal to, 15 microns).

Elutriators

Elutriators rely on gravitational settling to collect particles. An elutriator is made up of one or more vertical tubes or towers in series, where the gas stream passes upward through the tubes. Larger particles whose terminal settling velocity is greater than the upward gas velocity are collected at the bottom of the tube, while smaller particles are carried out of the top of the tube. Size classification of the collected particles can be achieved by using a series of tubes with increasing diameters.

Momentum Separators

Momentum separators utilize both gravity and inertia to separate particles from the gas stream. Separation is accomplished by forcing the gas flow to sharply change direction within a gravity settling chamber through the use of strategically placed baffles. Typically, the gas first flows downward and then is forced by the baffles to suddenly flow upwards. Inertial momentum and gravity act in the downward direction on the particles, which causes larger particles to cross the flow lines of the gas and collect in the bottom of the chamber. Momentum separators are capable of collecting particles as small as 10 microns at low efficiency (10-20 percent).

Centrifugal Collectors

Centrifugal collectors, sometimes referred to as mechanically aided separators, rely on inertia as a separation mechanism. The gas stream is accelerated mechanically, which increases the effectiveness of the inertia separation. As a result, centrifugal collectors can collect smaller particles than momentum separators. A common type of certrifugal collectors is the modified radial blade fan. In this device, the gas stream enters at the center of the fan, perpendicular to the blade rotation. The blades propel the particles across the gas flow lines, where they are concentrated on the inside wall of the casing. From there, the particles are diverted into a collection hopper while the gas continues out of the separator.

Cyclones

Cyclones are essentially cylinders with inlet and outlet ducts for the air stream. A vortex is created in the cylindrical section of the cyclone either by injecting the air stream tangentially or by passing the gas through a series of vanes. As the particulate-laden gas is forced to change direction in the vortex, the inertia of the particles forces them to continue in the original direction, collide with the outer wall, and slide downward to the bottom of the device to be collected in a hopper. The cleaned airstream passes upward and out of the cyclone. Particle separation is a function of gas throughput and the cyclone cylindrical diameter. Particle removal efficiency increases with increased flue gas velocity and decreases with decreased cylinder diameter. However, above an upper limit of flue gas velocity, increased turbulence can reduce particle removal efficiency.

Simple cyclones consist of an inlet, cylindrical section, conical section, gas outlet tube, and a dust outlet tube. Figure 12.4-10 is a schematic diagram of a typical cyclone. A multiple cyclone, or multiclone, consists of a number of small-diameter cyclones operating in parallel. This design takes advantage of the high efficiency of small diameter tubes and is capable of treating large gas volumes.

4.19.3 WHAT ISSUES ARE OF CONCERN WHEN USING MECHANICAL COLLECTORS?

The issues are:

- Plugging of the dust outlet tube can affect the performance of cyclones.
- With cyclones, abrasion can lead to leaks or rough areas on the surface of the cylinder that can cause local turbulence, reducing the effectiveness of the vortex in removing particles.
- The efficiency of multiple cyclones can be decreased by hopper recirculation which occurs when uneven pressure drops across the system result in reversed flow of the exhaust stream in some areas of the multiple cyclone.
- The abrasive wear from large particles and clogging from particles which accumulate on the fan blades can affect the efficiency of centrifugal collectors.

4.19.4 WHAT WASTES RESULT FROM USING MECHANICAL COLLECTORS?

Mechanical collectors collect dry particulate waste. To decrease the problems associated with handling fine dust, the collected particulate matter can be wetted in a pug mill into a clay-like consistency, or pelletized before it is recycled or landfilled.

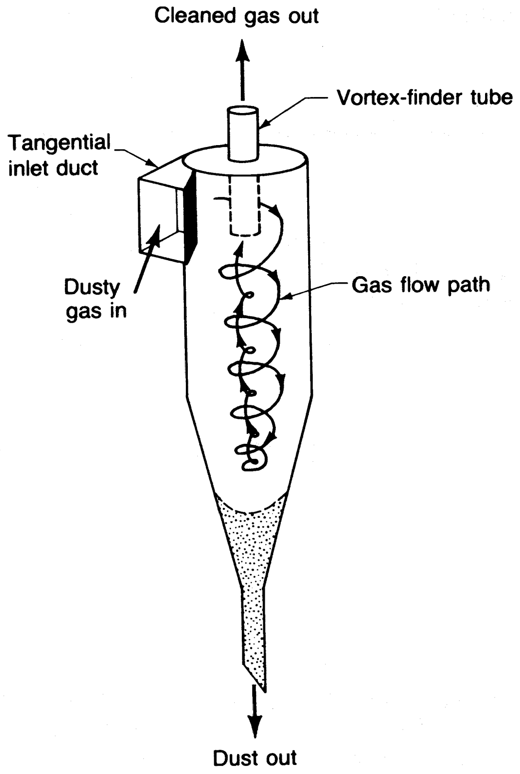

FIGURE 12.4-10. SCHEMATIC FLOW DIAGRAM OF A STANDARD CYCLONE (COOPER AND ALLEY, 1994)

4.20 ELECTROSTATIC PRECIPITATORS (ESP)

4.20.1 WHAT POLLUTANTS ARE CONTROLLED USING ELECTROSTATIC PRECIPITATORS?

Particulate matter emissions are controlled using ESPs.

4.20.2 HOW DO ELECTROSTATIC PRECIPITATORS WORK?

Electrostatic precipitators use an electrostatic field to charge particulate matter in the flue gas stream. The charged particles then migrate to a grounded collection surface. The collected particles are periodically dislodged from the collection surface by vibration or rapping.
An ESP is essentially a large box with a series of electrodes and grounded plates. Figure 12.4-11 is a schematic diagram of a typical ESP. ESPs use electrical forces to move the particles out of the flowing gas stream and onto the collector plates. Voltage is applied to the electrodes causing the gas between the negatively-charged electrodes to break down electrically, forming a “corona.” The ions generated in the corona follow electric field lines from the electrodes to the collecting plates; establishing charging zones through which the particles must pass. Particles passing through the charging zone intercept some of the ions, which become attached. As the particles pass each successive wire, they are driven closer and closer to the oppositely charged collecting walls, but the turbulence of the gas tends to keep them uniformly mixed with the gas. The collection process is a competition between electrical and dispersive forces. Eventually, the particles approach close enough to the walls so that the turbulence drops to low levels and the particles are collected. Refer to Figure 12.4-12.

Once the particles are collected on the plates, they must be removed from the plates without reentraining them into the gas stream. This is usually accomplished by knocking them loose from the plates, allowing the collected layer of particles to slide down into a hopper, from which they are evacuated. Because particulate tends to agglomerate, the ash layer is removed in sheets.

There are several common configurations for electrostatic precipitators:

- **Plate-wire precipitators** are the most common ESP configuration. In a plate-wire ESP, dirty gas flows into a chamber consisting of a series of discharge wire electrodes that are equally spaced along the center line between adjacent collection plates. Charged particles are collected on the plates as dust. Plate-wire ESPs can handle large volumes of gas and are used in coal-fired boilers, cement kilns, solid waste incinerators, paper mill recovery boilers, petroleum refining catalytic cracking units, sinter plants, basic oxygen furnaces, open hearth furnaces, electric arc furnaces, coke oven batteries, and glass furnaces.

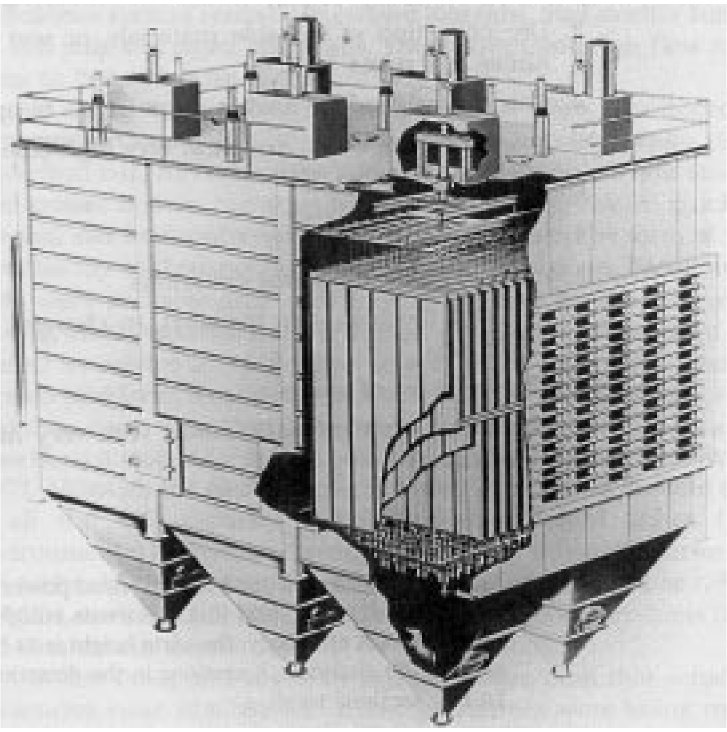

FIGURE 12.4-11. CUTAWAY VIEW OF AN ELECTROSTATIC PRECIPITATOR (COOPER AND ALLEY, 1994)

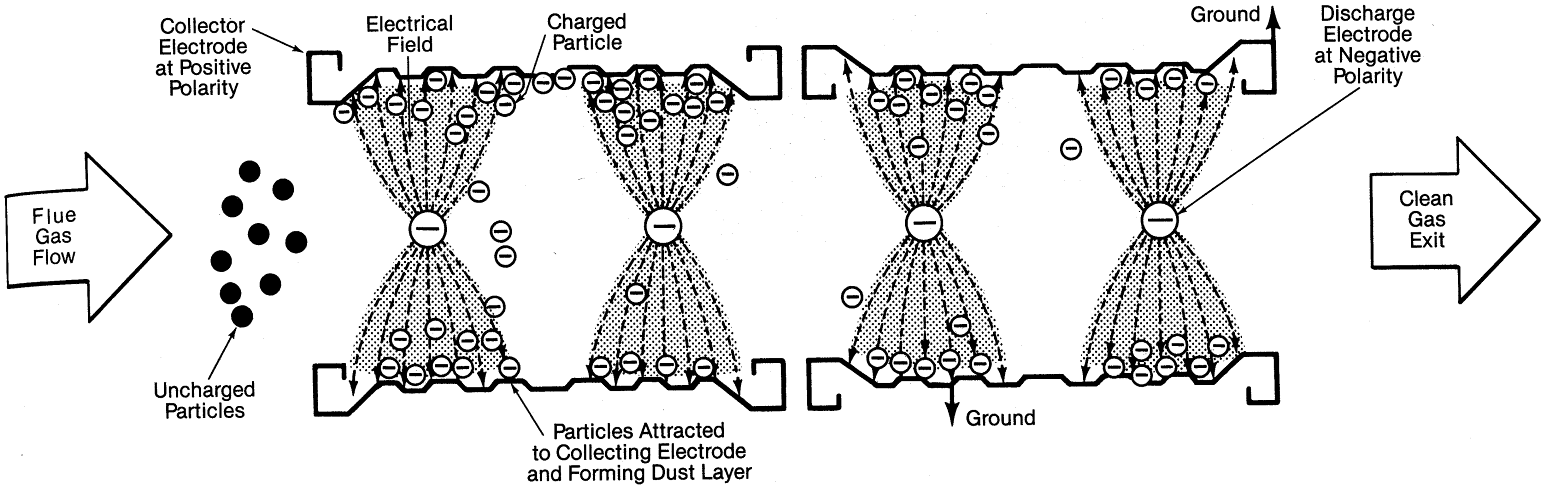

FIGURE 12.4-12. PARTICLE CHARGING AND COLLECTION WITHIN AN ESP (BABCOCK & WILCOX, 1992)

- **Rigid discharge electrode (RDE)** units have electrodes suspended from high-voltage frames located in the area above the gas passages. RDEs are currently the most popular configuration of ESPs. The discharge eletrodes are centered in the gas passages. In a common form of this design, sharp-pointed needles attached to a rigid structure are used as high-voltage electrodes instead of the electrodes hanging between plates of a plate-wire ESP. RDE units are typically used in the pulp and paper, ferrous and non-ferrous metals, petrochemical, cement, and waste-to-energy industries, as well as, electric power generating plants.

- **Wet precipitators** are plate-wire, flat-plate, or tubular ESPs operated with water flow applied intermittently or continuously to wash the collected particles into a sump for disposal. This configuration has the advantage that it eliminates problems with re-entrainment. Disadvantages of the configuration include increased complexity of the wash system and the fact that the collected slurry is more difficult and more expensive to dispose of than dry particulate matter.

4.20.3 WHAT ISSUES ARE OF CONCERN WHEN USING ELECTROSTATIC PRECIPITATORS?

The main issues affecting the control efficiency of an ESP are the design of the device and proper maintenance. The design of an ESP for a particular application is based on characteristics of the particulate matter that affect its ability to be collected and the gas volume flow rate. The ability of the particulate matter to be collected is affected by the particle migration velocity. The particle migration velocity is the rate at which the particle moves along the electric field lines toward the walls, where they are collected. Particle migration velocity is based on the estimated particle charge, mass of particles in the gas stream, and particle diameter and shape (size). These estimations aren’t always exactly correct because the particulate actually consists of particles of a wide range of sizes. Collection efficiency decreases as the particle diameter becomes smaller down to about 0.5 microns when Brownian Motion effects cause movement toward the collection surfaces. Therefore, the collection efficiency of PM_{10} and $PM_{2.5}$ is much lower than for total PM. The particle migration velocity is used to determine the specific collecting area (SCA) required to achieve the desired collection efficiency. The SCA is the ratio of the collecting surface area to the gas volume flow rate and is usually expressed in units of square feet of collection area per thousand actual cubic feet per minute of gas flow (ft^2/kacfm). The design total collecting area (size of the ESP) is determined by multiplying the SCA by the gas volume flow rate. ESPs are usually designed with more theoretical total collecting area than is required to achieve a guaranteed control efficiency. This minimizes the possibility of not meeting the guarantee because of changes in PM or flue gas characteristics. Thus, if flue gas parameters and particulate matter characteristics are not considered when designing the ESP, the control efficiency will not be at the desired level.

The electrical fields must be properly maintained in order for the ESP to achieve the desired control efficiency. Each electrical field in an ESP is composed of bus sections. If electrical power is lost to a bus due to grounding or other reasons, the bus will be out of service. Bus sections out of service directly in line between fields will reduce the control efficiency because some of the particles miss multiple active fields. To account for this, the number of bus sections per field in industrial ESPs has increased over the last couple of decades.

Simply operating the ESP will reduce the control efficiency over time. Non-removable dust buildup on discharge and collecting surfaces will inhibit current flow and particle charge resulting in fewer particles collected. Warping of components will shorten the distance from discharge to ground, and corrosion will create sharp edges that cause arcing. Both of these conditions reduce the discharge voltage and charge buildup on the particles, reducing the collection ability of the particles.

4.20.4 WHAT WASTES RESULT FROM USING ELECTROSTATIC PRECIPITATORS?

With the exception of wet precipitators, which generate liquid slurries, ESPs generate dry particulate waste. To decrease the problems associated with handling fine dust, the collected particulate matter can be wetted in a pug mill into a clay-like consistency, or pelletized before it is recycled or landfilled.

4.21 FABRIC FILTERS (FF)

4.21.1 WHAT POLLUTANTS ARE CONTROLLED USING FABRIC FILTERS?

Fabric filters, also referred to as baghouses, are used to control emissions of particulate matter and are capable of achieving the highest particulate removal efficiencies of all the particulate control devices. They do not have a declining collection effectiveness for smaller particles compared to other control devices. However, fabric filters are generally designed to reduce overall PM emissions to below an expected concentration when the inlet concentrations are within a specified range. The expected outlet concentration remains relatively “constant” even though the inlet concentration varies within the specified range. See Section 1.5 of this document for a discussion of the efficiency of fabric filters when used in series with other control devices.

4.21.2 HOW DO FABRIC FILTERS WORK?

A fabric filter system consists of several filtering elements (“bags”), a bag cleaning system, and dust hoppers contained in a main shell structure. Fabric filters remove dust from a gas stream by passing the stream through a porous fabric. The fabric does some of the filtering, but plays a more important role by acting as a support medium for the layer of dust that quickly accumulates on it. The dust layer ("cake") is responsible for the highly efficient filtering of small particles, but also increases the resistance to gas flow.

The major particle collection mechanisms of fabric filters are:

- **Inertial impaction** occurs as the flue gas stream flows through the fabric. As the gas stream approaches the fabric fibers, it accelerates and changes direction to pass around the fiber. Inertia will maintain the forward motion of the particles, and they will impact onto the surface of the fabric filter.

- **Collection by diffusion** occurs as a result of both fluid motion and the Brownian (random) motion of particles. Diffusional effects are most significant for particles less than 1 micron in diameter.

- **Interception or sieving** occurs when a particle comes within one particle radius of an obstacle.

There are three common fabric filter configurations; refer to Figure 12.4-13.

- **Reverse air baghouses** operate by directing the dirty flue gas inside the bags so that dust is collected on the inside surface of the bag. The bags are periodically cleaned by reversing the flow of air. This causes the dust cake to fall from the bags to a hopper below. In some configurations, the bags are shaken during the reversed air flow.

- **Shaker baghouses** are similar to reverse air units in that cleaning occurs on the inside surface of the bags. Unlike reverse air units, a mechanical motion is used to shake the bags and dislodge the accumulated dustcake.

- **Pulse jet baghouses** have an internal frame (cages) to allow collection of the dust on the outside of the bags. The dust cake is periodically removed by a pulsed jet of compressed air into the bag that causes a sudden bag expansion. Dust is primarily removed by inertial forces when the bag reaches maximum expansion. The vigorousness of the cleaning method and the fit of the bag against the cage may limit bag life and increase dust migration through the fabric. Pulse jet baghouses sometimes use pleated cartridges instead of bags.

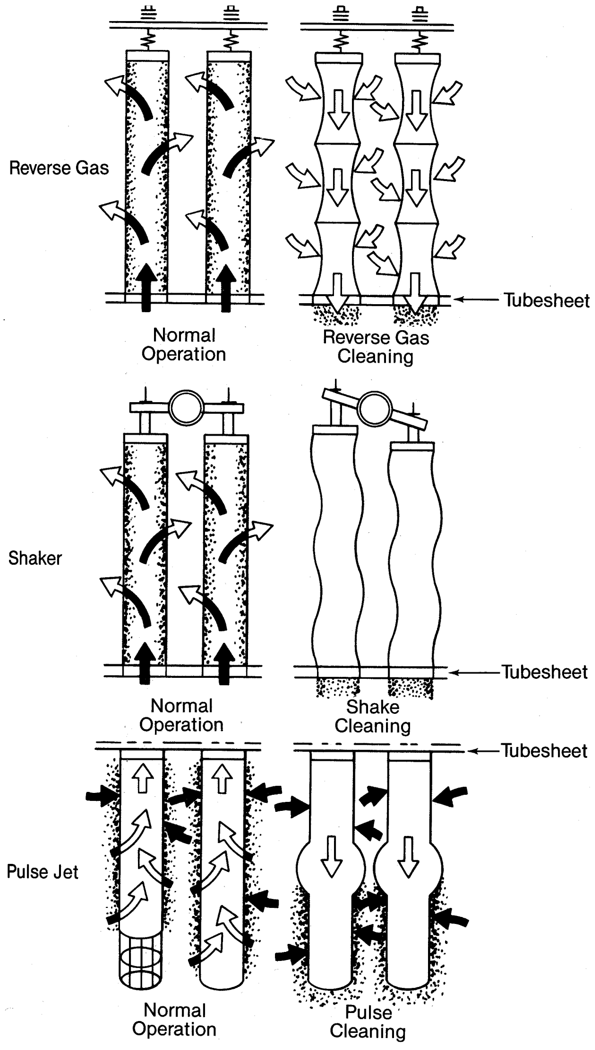

FIGURE 12.4-13. FABRIC FILTER TYPES (BABCOCK & WILCOX, 1992)

Removal of the dust from the fabric is a crucial factor in the performance of a fabric filter. If the dust cake is not adequately removed, the pressure drop across the system will increase to an excessive level. If too much cake is removed, excessive dust leakage will occur while the new cake develops.

Fabric selection (considering both material and type of weave) is important. The fabric must be matched properly with both the gas stream characteristics, and the type of particulate. The commonly used fabrics have very different abilities with respect to operating temperatures and chemical content of the gas stream. A bag life of 3 to 5 years is common. Refer to Table 12.4-1.

Successful operation of a fabric filter system depends on the proper selection of fabric and cleaning method and on an adequate air-to-cloth ratio. The air-to-cloth ratio (A/C), is a critical design feature of a fabric filter system. The A/C ratio is an important indicator of the amount of air that can be filtered in a given time when considering the dust to be collected, cleaning method, fabric type, and the characteristics of the gas stream to be filtered. The A/C ratio is a measure of the amount of gas driven through each square foot of fabric in the baghouse and is given in terms of the number of cubic feet of gas per minute flowing through 1 square foot of cloth. The A/C ratio is more correctly referred to as the media face velocity because it is not the actual velocity of the gas stream through the openings in the fabric, but the velocity of the gas approaching the cloth. In general, as the A/C ratio increases, the efficiency of impaction collection increases and diffusional collection efficiency decreases. However, as the A/C ratio continues to increase, there is an increased pressure drop, increased particle penetration, blinding of fabric, need for more frequent cleaning, and reduced bag life.

4.21.3 WHAT ISSUES ARE OF CONCERN WHEN USING FABRIC FILTERS?

While many different types of media are used in fabric filters dust collection is not usually an issue if filter bags are in good condition. Emissions may still vary based on the media used. Bags coated with a porous surface membrane such as Teflon® are extremely effective. Felt tends to be more effective than woven fabric since it collects new particulate better, just after bag cleaning, before the dust cake reestablishes itself.

TABLE 12.4-1

TEMPERATURE AND CHEMICAL RESISTANCE OF SOME COMMON INDUSTRIAL FABRICS USED IN FABRIC FILTERS

Fabric	Recommended Maximum Temperature °F	Chemical Resistance	
		Acid	Base
Dynel[a]	160	Good	Good
Cotton[a]	180	Poor	Good
Nylon[a]	200	Poor	Good
Polypropylene[a]	200	Excellent	Excellent
Dacron[a]	275	Good	Fair
Nomex®[a]	400	Fair	Good
Teflon®[a]	400	Excellent	Excellent
Fiberglass	550	Good	Good
P84 (polyimide)[b]	500	Fair	Good
Ryton (polypropylene sulfide[b]	375	Good	Good
Expanded PTFE[c]	500	Good	Excellent

[a] Cooper, C.D., and F.C. Alley. 1994.
[b] Manufacturer's literature.
[c] Loeffler, Dietrich, and Flatt. 1988.

Fabric filters have several limitations:

- The media or, in the case of cartridge type filters, glue attaching the cartridge to its end flanges limits flue gas temperature to about 550°F. Many types of material of different properties and cost are available within this range.
- The unit cleaning mechanism must be able to remove the dust cake well enough so that its resistance to gas flow does not cause the pressure differential to exceed the intended value across the bags. Hygroscopic material or condensation of moisture can cause a permanent caking or "blinding" of the media. Some dusts are generally removed from the bag, but enough residual cake is left so that, after cleaning, a permanent flow resistance is provided. This would require a lower gas velocity, meaning more filter media, to maintain the desired pressure drop. High pressure drop across cleaned bags causes a rapid cleaning rate, shortening the life of the bags.
- The filter media may be subject to chemical attack. Acids, alkalis, etc., may attack the media.
- Hot or burning embers may enter the unit and damage the media.
- Combustible dusts can create a fire hazard. Fine dust can create a fire or explosion hazard.

These problems are dealt with in selecting the composition and construction of the filter media. Filter bag cost is also a major consideration in selection.

Dust cleaning causes the bags to weaken and fail over time. It is necessary to maintain a desired pressure drop across the bags to protect the media, to minimize the number of times the bags are cleaned, and possibly to provide a constant gas flow from the emission process. In some units, a single compartment in the fabric filter is cleaned at a time, triggered when a fixed pressure drop is reached. Units with pulse jet cleaning usually clean a small number of bag rows when triggered.

Ensuring control of emissions from a fabric filter is based on inspection and maintenance of the bags and other components. Holes in bags cause jets of dirty gas that rapidly destroy surrounding bags by abrasion. Inspections should be frequent enough to limit this damage. Dust sensors at the compartment outlet may sense this problem during operation or during bag cleaning. Dust falls on top of the tubesheet (see Figure 12.4-13) when a bag leaks during operation. In a pulse jet collector, this may be noticed as a sudden increase on an opacity meter beyond the fabric filter outlet when the cleaning air pulse suspends dust already on the tubesheet floor. The compartment with filter damage can be determined in this case.

The indications that bags are leaking require a prompt inspection of the bags and replacement of the damaged filters. A delay causes excess emissions and additional bags to fail.

4.21.4 WHAT WASTES RESULT FROM USING FABRIC FILTERS?

Fabric filters generate dry particulate waste. To decrease the problems associated with handling fine dust, the collected particulate matter can be wetted in a pug mill into a clay-like consistency, or pelletized before it is recycled or landfilled.

4.22 WET PM SCRUBBERS

4.22.1 WHAT POLLUTANTS ARE CONTROLLED USING WET PM SCRUBBERS?

Wet PM scrubbers control PM and acid gases, with some control of organics. Wet PM scrubbers are applied as a post-process technique to:

- Scrub particulates from incinerator exhausts;
- Control particulate and gaseous emissions simultaneously;
- Control acid gases;
- Control sticky emissions that would otherwise plug filter-type collectors;
- Recover soluble dusts and powders; and
- Control metallic powders such as aluminum dust that tend to explode if handled dry.

4.22.2 HOW DO WET PM SCRUBBERS WORK?

Wet PM scrubbers remove particles from gas by capturing the particles in liquid droplets (usually water) and separating the droplets from the gas stream. Wet PM scrubbers are configured to create a closely packed dispersion of fine droplets to act as targets for particle capture. The goal is to cause the tiny pollutant particle to be lodged inside the collecting droplet and then to remove the larger droplet from the gas stream. In general, the smaller the target droplet, the smaller the size of particulate that can be captured and the more densely the droplets are packed, the greater the probability of capture.

Particles are captured by liquid droplets through three mechanisms; refer to Figure 12.4-14:

- **Impaction** of the particle directly into a target droplet;
- **Interception** of the particle by the target droplet as the particle comes near the droplet; and
- **Diffusion** of the particle through the gas surrounding the target droplet until the particle is close enough to be captured.

There are several types of wet PM scrubber configurations, differing in the systems used to create the droplet dispersion:

- **Venturi scrubbers** are highly effective particulate control devices, but they consume large amounts of energy, resulting in high operating costs. Venturi scrubbers generate fine droplet dispersion by pneumatically atomizing the scrubbing liquid in a high-velocity zone called the venturi throat. Target droplets are dispersed by accelerating the gas stream to a high velocity and then using this kinetic energy to shear the scrubbing liquid into fine droplets. The accelerating force comes primarily from gas-stream kinetic energy, usually injected into the system by a fan.
- **Mechanically aided scrubbers** create droplet dispersion by a whirling mechanical device, usually a fan wheel or disk. Liquid is injected into or onto the disk and mechanical energy is added to break the liquid into fine droplets. Mechanically aided scrubbers differ from venturi scrubbers in that mechanical energy is applied to the system while venturi scrubbers apply only pneumatic shearing. Mechanically aided devices use lower fan energy than other devices; but on a total energy-input basis use more energy because the collection energy comes from supplemental, driven energy.
- **Pump-aided scrubbers** are eductor-type venturi scrubbers that use high-velocity liquid spray to entrain the gas and pull it through the unit. Most of the energy input comes from the pressurized liquid stream.
- **Wetted filter scrubbers** force the liquid and gas through a medium with small openings. A filtration-like process occurs, with the particulate temporarily

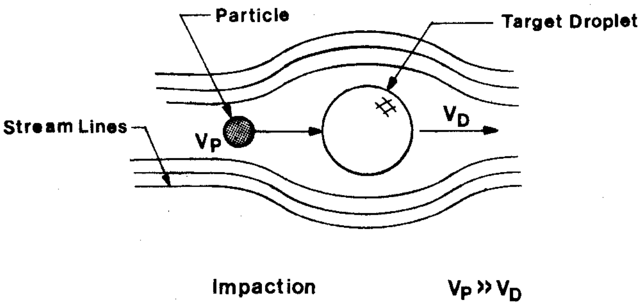

FIGURE 1. Most Particles Are Removed by Direct Impaction into a Droplet

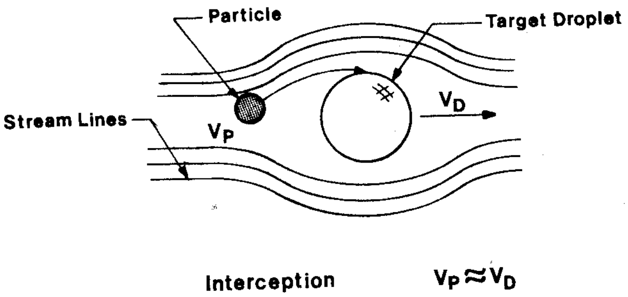

FIGURE 2. Other Particles Come Close to the Droplet and Are Intercepted

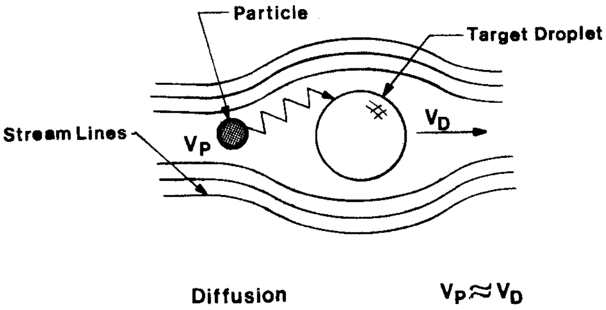

FIGURE 3. Smaller Particles Are Captured by Diffusion

FIGURE 12.4-14. SCHEMATIC OF HOW WET PM SCRUBBERS REMOVE PARTICLES (AWMA, 1992)

sticking to the filter. Wetted filter scrubbers are sometimes used in series and usually used for low particulate loadings.

- **Tray or sieve scrubbers** have no large gas-directing baffles, but are simply perforated plates (or trays) with small orifices that accelerate the gas stream. The trays are held in a tower, usually immediately downstream of a venturi. A water level is maintained above the trays (there are usually 2 or more trays). The particulate is injected into the liquid stream, using the energy of the gas. The geometrical relationship of the tray thickness, hole diameter and spacing, as well as the impinger details, results in a high-efficiency device for the removal of small particulate of less than 2μm in mean diameter. Refer to Figure 12.4-15. **Impingement tray scrubbers** are tray scrubbers with target baffles.

A critical component of effective wet scrubbing for PM is efficient removal of the residual droplets or mist. Common mist eliminator configurations include:

- **Cyclonic droplet removal** which uses centrifugal force. Tangential velocity is created through the use of vanes, rotating elements, or tangential gas inlet into a cylindrical vessel. The cyclonic action throws the liquid against the vessel wall, where it drains by gravity or is trapped.

- **Chevron droplet removal** which is applicable for vertical or horizontal gas flows. Flue is zig-zag shaped, with blades running parallel to the surface. The inertia of the droplet tends to carry it straight ahead, so the droplets impact on the blade surface, accumulate, and drain.

- **Mist pads**, are used to coalesce fine liquid droplets until they enlarge enough to fall, by gravity or capillary action, out of the pad. These are most often used where little or no particulate is present.

4.22.3 WHAT ISSUES ARE OF CONCERN WHEN USING WET PM SCRUBBERS?

The issues are:

- Droplet entrainment in the flue gas can increase the opacity of the plume;

- Wet systems cause more corrosion problems than dry systems; and

- Solids build-up at the wet-dry interface can be a problem.

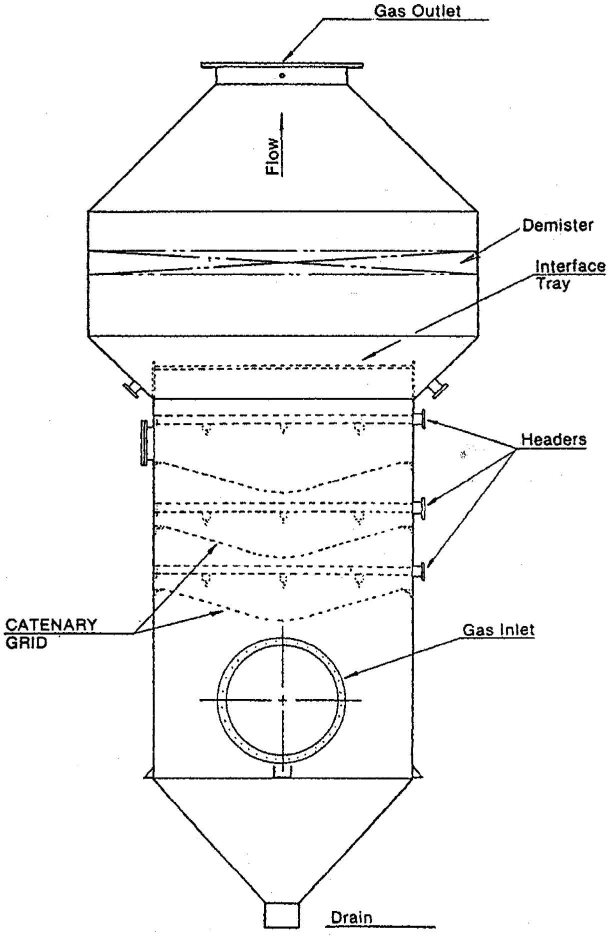

FIGURE 12.4-15. TRAY- OR SIEVE-TYPE SCRUBBER (CATENARY GRID SCRUBBER^{TM}) (AWMA, 1992)

4.22.4 WHAT WASTES RESULT FROM USING WET PM SCRUBBERS?

Wet PM scrubbers generate a waste slurry. This slurry can present a waste water treatment problem. The chemical and physical routine of the particulate matter being collected determine the ultimate disposal method of the slurry. If a scrubber is used to remove organic vapors, it is important that they are released at the waste water treatment process.

4.23 WHEN ARE MULTIPLE CONTROL DEVICES USED?

Multiple control device types may be used in combination to control either a single pollutant or multiple pollutants. For example, mechanical collectors are often used with fabric filters to control PM emissions. The mechanical collector collects large particles and the fabric filter collects smaller particles. Also, SCR is often used with fabric filters to control NO_x and PM emissions. The devices are arranged in series, or tandem, relative to the flue gas stream. The specific types of devices used and the order in which they are arranged is dependent on the process, gas stream, and pollutant characteristics. The overall control efficiency for multiple devices is likely to be around the efficiency of the last device in the series (see Section 1.5 of this document).

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5

EFFECTS OF AIR POLLUTION CONTROL DEVICE MALFUNCTIONS ON EMISSIONS

Excess emissions due to a malfunctioning control device can significantly increase the annual emissions of a source, even if the malfunctions occur for only a small percentage of the operating time. These emissions can be difficult to quantify, but if they are not accounted for, statewide emission inventories can be understated. For example, the efficiency of an electrostatic precipitator can be altered as a result of changes in process, including feedstock changes, which result in flow variation, changes in particle resistivity or other modifications of pollutant characteristics. The effects of such changes on efficiency are not always analyzed or considered when estimating emissions and compiling inventories. This section provides:

- A brief discussion of how excess emissions from control device malfunctions can affect statewide emission inventories; and

- Methods for calculating excess emissions due to a malfunctioning control device.

5.1 EXCESS EMISSIONS FROM AIR POLLUTION CONTROL DEVICE MALFUNCTIONS

5.1.1 WHAT ARE SOME EXAMPLES OF EXCESS EMISSIONS?

The following examples are taken from actual malfunction reports or other reports provided to various state agencies:

Example 1 -- VOC emissions from a loading station

> A malfunction was reported for a truck loading rack for gasoline and diesel in which the pump to the vapor recovery unit (a carbon adsorber) failed for 55 minutes. According to the malfunction report provided to the permitting agency, approximately 199 pounds (lb) of excess VOC emissions were released during this incident. This was the only reported incident for the quarter. While 199 lb of unexpected VOC may not appear significant, the potential accumulated

annual emissions that may result from multiple events at multiple facilities in an inventory area could be significant.

Example No. 2 -- SO_2 emissions from a manufacturing process.

A sulfur recovery unit malfunctioned for 3 hours which resulted in an overload of process gases through an oxidizer. The facility estimated that 1 ton of SO_2 in excess of permitted levels was released during this malfunction.

Example No. 3 -- VOC emissions from a manufacturing process

In one instance, a dirty flame arrestor on an incinerator reduced the oxidizer chamber temperature for 1 hour and 4 minutes. The facility estimated that 983 lb of VOC in excess of permit levels was released during this malfunction.

5.1.2 WHAT ARE SOME SPECIFIC CAUSES OF EXCESS EMISSIONS FROM CONTROL DEVICE MALFUNCTIONS?

These are just a few examples reported in one state's excess emissions database:

Event	Duration
"The cause of the excursion was due to a bad dust collector pulse valve."	1 hour, 13 minutes
"The LVHC stream was being combusted in the No. 1 combination boiler. The flame scanner on the boiler malfunctioned and the burner flame was not detected by the scanner. The indication of loss of flame by the scanner resulted in the removal of the LVHC."	2 hours, 2 minutes
"The heat exchangers were plugged with pulp."	8 days
"Faulty pump seal."	3 hours, 10 minutes
"Power failure in the system."	13 hours, 53 minutes
"A fuse blew on the control panel for scrubber number 1940sr050, which controls emissions for calciners number 1940ca010 and 1985ca010. The failure of the control panel caused a shutdown of the thermal oxidizers for both calciners and the opening of the designated emergency vent."	20 minutes
"Scrubber not functioning properly."	1 hour, 30 minutes
"The air pressure was lost to the system and the valve failed in the open position."	2 hours, 15 minutes

5.2 IMPACT OF EXCESS EMISSIONS

5.2.1 WHY ARE MALFUNCTIONING CONTROL DEVICES A CONCERN?

Equipment malfunctions result in increased emissions and can be a recurring problem at some facilities because of old or poorly maintained equipment or because of the nature of the process. Excess emissions due to a malfunctioning control device can significantly increase the annual emissions of a source, even if the malfunctions occur for only a small percentage of the operating time.

The seriousness of the excess emissions problem has resulted in regulatory actions in many states which require facilities to report all incidents of excess emissions to the regulatory agency. However, there is no guarantee that all incidents are reported. Some states focus their enforcement actions on sources that operate below their target control level more than 5 percent of the time. Examples presented in this section show malfunction times of even 1 or 2 percent per year can have a significant impact on emissions.

5.2.2 WHY IS IT IMPORTANT TO TRACK THESE EMISSIONS?

A few hours per month of excess emissions can quickly add up to 5 percent, 25 percent, or even more than 50 percent of the expected emissions for the entire year, if the emissions inventory is calculated on the basis of specified control levels.

For example, consider a source that is expected to emit 10 tons tpy of PM calculated on the basis of a 99 percent control level using an ESP and a 1,000 tpy uncontrolled emission rate. If this source operates at 4,800 hours per year, and if the ESP lost partial field voltage for only 4 hours per month (i.e., 1 percent of the total operating hours) resulting in the control efficiency dropping from 99 percent to 75 percent during the malfunction, actual annual emissions would increase from 10 tpy to 11.4 tpy. This equals an increase in emissions of 14 percent. If these conditions were typical for the source category, then the emission inventory for the source category would need to be increased by 14 percent to correct for emissions from the APCD malfunctions.

5.2.3 HOW DO EXCESS EMISSIONS FROM AIR POLLUTION CONTROL DEVICE MALFUNCTIONS AFFECT EMISSION INVENTORIES?

Excluding excess emissions can result in an understated annual emission inventory. Emission inventories are typically based on the “normal” level of emissions specified in rules that apply to a set of sources. However, both federal and state rules may explicitly allow for short-term exceedance of the normal control level or emission limits (whether due to malfunctions, startup and shutdown, or other conditions). One example is the new source performance standard

(NSPS) for electric utility steam generating units (40 CFR Section 60.40 Subpart Da; 44 FR 33613, June 11, 1997). This standard incorporates compliance provisions to allow for PM and SO_2 exceedances during startup, shutdown, or malfunction, given "emergency conditions" are implemented to minimize emissions during these events.

The inventory preparer should be aware that "excess emissions or malfunction" reports are required by most state agencies. When preparing the inventory, these reports should be reviewed for applicable information to determine the duration and degree of malfunctions.

5.3 ACCOUNTING FOR EXCESS EMISSIONS IN AN EMISSION INVENTORY

5.3.1 WHAT IS THE EFFICIENCY OF THE CONTROL DEVICE DURING PROCESS UPSET CONDITIONS?

Data are not always available to offer quantitative estimates of control device efficiencies during process upsets. Generally, only process upsets that overload the control device system will affect the amount of emissions released. You should consult with process engineers and other experienced emission inventory preparers to determine these effects on emissions. Most often, state compliance and permitting staff will be the best sources of information regarding the expected effects.

5.3.2 HOW CAN RELEASES DURING CONTROL DEVICE MALFUNCTIONS BE CALCULATED?

If you know or can estimate control efficiencies during malfunction conditions, the emission calculations are straightforward. Appendix E contains two example calculations where malfunction conditions are known. Example E-1 shows the calculated emissions increase for a coke and coal-fired boiler with an ESP that loses partial field voltage for several hours each month. Example E-2 shows the emissions increase for a wood dryer that emits PM_{10} and VOC. The tables and figures in Appendix F show the emission increases for other scenarios in which you have an estimate of the emission rate increase during a malfunction.

Note, that some other types of malfunction estimates are more difficult, if not impossible, to calculate accurately. Conditions such as the following will require greater use of engineering judgment in developing estimates:

- PM emission increases that are estimated only by opacity readings;

- VOC emission increases from enclosed systems (e.g., vapor recovery systems) that have partial loss of vacuum or air flow;
- Fugitive losses; and
- Irregular emissions during process startup and shutdown, including particulate emissions shortly after fabric filter shakeout.

5.3.3 FOR THOSE CASES IN WHICH EXCESS EMISSIONS FROM CONTROL DEVICE MALFUNCTIONS CAN BE REASONABLY ESTIMATED, HOW CAN YOU COLLECT THE RELEVANT DATA?

In some cases, these calculations may already be in your inventory. For example, utility boilers will have likely incorporated malfunction emissions into the quarterly emission reports that they must file (required by the NSPS) with your state agency. It is important to make sure that these emission estimates are incorporated into the emission inventory.

If your state requires facilities to estimate emission exceedances during malfunctions, compliance staff may have records of these estimates. However, this type of information for sources other than utility boilers is rarely transferred from the compliance or permitting staff files to the state emission inventory files. You will often have to confer with the compliance or permitting staff to obtain these figures. Compliance or permitting staff are probably the best sources of information regarding how frequently sources operate with malfunctioning control equipment, and regarding the estimated magnitude of these emissions. You can supplement this information with other data from regulations, engineering guidance, and other sources. Appendix G provides a general list of data sources.

5.4 CONCLUSION AND COMMENT SOLICITATION

The information presented in Section 5 of this document has been derived from preliminary conversations with permitting and inventory staff in only a few states. However, it is evident that excess emissions due to control device malfunctions may have a significant impact on individual source emissions and on statewide emission inventories that are based strictly on emission levels specified in regulations or permits. Furthermore, excess emissions from control device malfunctions may have a more severe impact on source compliance than has been previously expected or reported.

The EIIP Point Sources Committee would like to improve our understanding of the actual impact of control device malfunctions on emission inventories and would like to share this data with emission inventory preparers throughout the United States. If you have comments on this document, and particularly if you have data that can refine our understanding of this subject, please contact us.

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APPENDIX A

EPA'S DRAFT PAPER *CLEARING UP THE RULE EFFECTIVENESS CONFUSION*

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Clearing Up The Rule Effectiveness Confusion

Introduction

Since its formation, EPA has been implementing rules and regulations that require states to reduce the amount of pollution being emitted into the atmosphere. Achieving the air quality anticipated by implementing a particular rule has not always been successful despite imposition of numerous emission controls. In 1987 EPA acknowledged that existing air quality regulations were not resulting in sufficient emission reductions to reach acceptable levels of air quality. The November 24, 1987 Federal Register said "The EPA believes that one reason ozone levels have not declined as much as expected is that reductions from national and local control measures have not been as high as expected."(1) This Federal Register further stated that "the effectiveness (i.e., the ratio of actual reductions to expected reductions expressed as a percentage) of some rules is much lower than 100 percent." To correct or compensate for the lower than anticipated amount of reductions, the Federal Register notice stated that "for both new and existing rules, EPA proposes to allow States to assume not more than 80% of full effectiveness unless adequate higher levels are adequately demonstrated." Said another way, "we don't believe your rule will get as much reduction as you think it will." This under-performance can result from:

* some sources not implementing (or not implementing all the time) controls required by the rule,
* some sources not installing sufficient control equipment to achieve required emission rate,
* some sources operating installed control equipment at less than rated control efficiency,
* new source being introduced into the local area covered by the rule.

Any of these situations could result in attainment year emissions being higher than anticipated. Even though an individual source's emission rate is reduced to that specified in a state rule, the overall reduction within the state may not be as great because of the above considerations.

The 1987 Federal Register (1) defines “effectiveness” as:

$$\text{effectiveness} = \frac{\text{Actual Reductions}}{\text{Expected Reductions}} \qquad (1)$$

For complete compliance to occur, effectiveness must equal 100%. This Federal Register recognizes however, that effectiveness is usually not 100%. To adjust for non-compliance, the Federal Register limits the amount of reduction that a state can anticipate. This forces policy planners to account for less than complete compliance. For example, if an agency implemented a rule to reduce emissions by 100t/y (expected reduction), the Federal Register suggests that the actual reduction will not be as great as the expected reduction (Equation 1). For the 100t/y goal to be met (i.e., “effectiveness” to be 100%), the actual reduction in Equation 1 must be modified as follows:

$$\text{effectiveness} = \frac{\text{Reduction target * (Empirical Factor)}}{\text{Expected Reduction}} \qquad (2)$$

where:

Expected Reduction = Emission reduction required as estimated by modeling to meet air quality standard

In this example, equation 2 becomes:

$$100\% = \frac{\text{Reduction target * 0.8}}{100}$$

Solving for Reduction target: Reduction target = 125t/y

Policy makers then develop control strategies based on this Reduction target value. If an agency implements a rule to reduce emissions by 100t/y, the policy makers must target a 125t/y reduction to be able to achieve the needed 100t/y. Note that the results of equation 2 do not reflect the accuracy of the emission estimates, but only adjust for the past history of complying with a new rule.

The 1992 Federal Register (2) defines rule effectiveness as:

$$\text{Rule Effectiveness (RE)} = \frac{\text{Actual reduction}}{\text{Expected reduction}} \qquad (3)$$

where:

Actual reduction = (base year emissions) - (current year emission estimates)

In equation 3, the new term “RE” is an indicator that compares the amount of actual emission reduction to the expected reduction. This metric is useful to decision makers as they evaluate how well their policies are achieving the intended goals or how effective the rule is in achieving expected reductions. For example, assume an agency modeling exercise indicated that 100t/y reduction is needed in 10 years to be able to reach attainment status. Also assume the base year inventory is 200t/y. If a 50t/y reduction is achieved 5 years into the implementation period, then the RE = (200 - 150)/100 = 50%. At the end of 10 years, if the entire 100t/y has been removed, then the RE = (200 - 100)/100 = 100%.

Introducing the factors contained in these equations acknowledges the reality that, in an imperfect world, a rule intended to reduce emissions and improve air quality does not always work as planned. Equation 2 offers, for planning purposes, an empirical solution to this problem while Equation 3 measures the effectiveness of the solution after controls are implemented. The empirical approach assumes that only 80 percent (or higher if an agency can substantiate) of the required control will be achieved. To offset this shortfall, additional controls are needed. This concept was further supported in the April 16, 1992 Federal Register(2). Under III(A)(2)(a)(2) it is stated that “one hundred percent rule effectiveness is the ability of a regulatory program to achieve all the emission reductions at all sources at all times.” The “extra” controls in Equation 2 compensate for parts of the air quality strategy that are not completely implemented “at all of the sources all of the time”.

As the air quality control community became more sophisticated, it realized that other causes could be contributing to the inability to reach acceptable air quality levels. Two areas of concern are the accuracy of air quality model predictions (air quality modeling issues will not be addressed in this discussion) and the accuracy of the emission inventory accounting process (quantity of emissions represented in the inventory). Policy makers use emission estimates to help develop new rules that will cause the removal of a specified quantity of pollutant. They assume that removing this amount of pollutant will lead to acceptable air quality. The amount to be removed is usually selected as a result of various air quality modeling exercises. If the initial quantity of emissions used in the model calculations is incorrect, then the amount of pollutant to be reduced, as calculated by the model, may also be incorrect.

To offset an assumed underestimate of emissions, states are required to apply a compensation factor to facility control device efficiency values. This action has the effect of reducing the assumed efficiency of the control device (a reasonable assumption since control equipment may fail, be off line due to equipment maintenance, and process upsets occur) and increasing individual source emission estimates. This factor, also called Rule Effectiveness, has a default value of 80 percent.

Very few sources measure their emissions directly using Continuous Emission Monitors (CEM). Uncontrolled emissions at sources not monitored by CEMs are estimated using the following equation:

$$\text{emissions} = \text{emission factor} * \text{activity data} \qquad (4)$$

If RE is used, the equation to calculate emissions from a facility containing a control device becomes:

$$\text{emissions} = \text{emission factor} * \text{activity data} * (1 - CE * RE) \qquad (5)$$

where: CE = manufacturer stated control efficiency

The definition of RE in Equations 3 and in Equation 5 are very different. Equation 3 provides policy makers with a method to measure the amount of reduction at a point in time and judge the success of a particular rule. Equation 5 adjusts individual facility estimates to compensate for assessment techniques that do not account for all emissions. Even though the philosophy behind the emission adjustments is different in each case, the same term - RE, is used for both situations.

Why Confusion Exists

In 1992, EPA issued “Guidelines for Estimating and Applying Rule Effectiveness for Ozone/CO State Implementation Plan Base Year Inventories.”(3) Under section 1.2 the document states “The appropriate method for determining and using RE depends upon the purpose for the determination: compliance program or inventory. RE discussed outside the particular purpose may be generically referred to as control effectiveness. The following three common uses for a control effectiveness estimate have historically been called rule effectiveness:

* Identifying and addressing weakness in control strategies and regulations related to compliance and enforcement activities (more accurately call *Compliance Effectiveness*)

* Defining or redefining the control strategy necessary to achieve the required emissions reductions designated in the CAAA (more accurately called *Program* or SIP *Design Effectiveness*)

* Improving the accuracy or representativeness of emission estimates across a nonattainment area (hereafter called *Rule Effectiveness*)”(3)

“The inventory RE is an adjustment to estimated emissions data to account for the emissions underestimates due to compliance failures and the inability of most inventory techniques to include these failures in an emission estimate. The RE adjustment accounts for known underestimates due to noncompliance with existing rules, control equipment downtime or operating problems and process upsets. The result is a better estimate of expected emission reductions and control measure effectiveness in future years".(3)

Previous paragraphs provide definitions of Compliance effectiveness and Rule effectiveness and try to make a distinction between the two. Despite these distinctions, the second sentence of the preceding paragraph inadvisely combines concepts of both rule noncompliance and the problem of overestimating collection efficiency of control equipment. Even though there is a recognition that the two situations are different, the RE term is used interchangeably in each of these examples.

Rule Effectiveness Guidance: Integration of Inventory, Compliance, and Assessment Applications(4) was issued in January 1994. In the Introduction, the document states that "Rule Effectiveness (RE) is a generic term for identifying and estimating the uncertainty in emission estimates caused by failures and uncertainties in emission control programs. It is a measure of the extent to which a rule actually achieves its desired emission reductions." Implying a second definition, the Introduction further states that "rule effectiveness accounts for identifiable emission underestimates due to factors including noncompliance with existing rules, control equipment downtime, operating and maintenance problems, and upsets." As was previously noted, the RE term is again used in different contexts within the same section of the same document.

This Guidance document(4) contributes further to the confusion by using apparently different definitions of rule effectiveness. The Glossary defines Rule Effectiveness as "a generic term for identifying and estimating the uncertainties in emission estimates caused by failures and uncertainties in emission control programs. Literally, it is the extent to which a rule achieves the desired emission reductions."

Based on past history it is understandable that, over time, the inventory community has used RE to describe different situations and often interchanging the definitions during the same discussion. The RE definition has evolved, taking on slightly different meanings, depending on the group using the term and the program to which it is being applied. Confusion results because the inventory community often uses the term RE without indicating the context in which it is being applied. Mangat, in a paper(5) presented at an emission inventory conference in 1992 and in a subsequent EIIP paper (6), recognized that dissimilar definitions were being used and tried to explain the differences.

Solutions to the Confusion

RE is currently being used to describe and solve unrelated problems. In one case it is being used to address the failure of control equipment to operate at its stated efficiency for 100% of the time. In the second case RE is being used to address the failure of people to implement a rule with the required vigor.

Applying an adjustment factor is a valid approach in each of these situations. Unfortunately, the same term (RE) is used to describe and address both cases. The inventory community does not need more jargon. However, a solution to the current dilemma is to abandon the RE name and replace it with two distinctive terms, each describing specifically the situation in which it applies. Separate definitions should allow those interested in measuring how well a rule is achieving its intended reductions to determine those results. Those interested in adjusting actual emission estimates to compensate for upsets, downtime, etc could also meet their needs. Each new term is described below.

The **Practical Compliance Index (PCI)** is to be used by those in policy positions to measure how well a rule is achieving its intended results. The PCI is a measure of the extent to which a rule actually accomplishes its desired emission reductions. For example, if a new rule has a PCI of 80%, it has caused 80% of the needed emission reductions to occur. A 100% of the expected reductions did not (has not) occurred because not all facilities implemented controls mandated by the rule, some facilities did not control at the emission rate required by the rule, or unanticipated growth occurred in the area. Additionally, policy makers using historical PCI values can develop realistic control strategies for their area.

The **Operational Adjustment Factor (OAF)** is to be used to adjust control efficiency ratings of control devices. Adjustments are necessary due to control equipment down time, subpar control device operations, and process upsets. Current methods of estimating emissions do not account for these situations. The OAF will not be used to adjust emission factors, activity data, or direct measurement of emissions.

How to Apply a PCI and an OAF

PCI

Air quality modeling is performed to support new rule development. Models are run to determine how much pollutant should be removed from the air to reach an acceptable ambient air quality concentration level. When the new rule is implemented, a strategy is developed, based on model results, that describes the sources to be controlled and the acceptable emission rate of each source.

The Practical Compliance Index (PCI) provides policy makers with two tools. The Index measures how well the control strategy is progressing toward reaching the air quality goal. The PCI is calculated by:

$$\text{PCI} = \frac{\text{(Base year emission estimate) - (Current year emission estimate)}}{\text{Expected reduction}} \qquad (6)$$

The PCI measures progress toward meeting the new emission target in the designated attainment year. PCI can be calculated periodically to provide policy makers with information on how the policy is being implemented and the extent of compliance with new control requirements.

Past experience has shown that, even if after a new rule is fully implemented, the ambient air quality level still exceeds the standard. One reason for this failure is lack of compliance with a new rule. Policy makers can use this information to increase the likelihood that future emission targets will be met. This can be done by using an empirically derived factor that is used to adjust Equation 6. Even though the air quality modeling indicates a certain number of tons of pollutant are needed to be removed to reach the standard, practical experience shows that, without additional emphasis, this target will not be reached. The compensation factor in equation 6a offsets this lack of compliance. If the goal is to achieve a 100% PCI, then equation 6 becomes:

$$\text{PCI} = \frac{\text{Reduction target * Compensation factor}}{\text{Expected reduction}} \qquad (6a)$$

Where: Compensation factor has a default value of 80%

The denominator is the amount of reduction necessary, as calculated by air quality modeling, to achieve acceptable ambient air pollutant levels. By setting the PCI to 1 (100%) and solving for the Reduction target in the numerator, policy makers will know how much pollutant reduction should be targeted for their control strategies. The compensation factor is analogous to the definition of RE in equation 3. Guidance currently being used to calculate a RE factor can be used to estimate the compensation factor in equation 6a.

OAF

An inventory is composed of data that are used to estimate emissions. It contains information on control efficiencies of the devices connected to the processes being inventoried. Actual emissions are estimated either from direct measurements of the source or from calculations using variables contained in the inventory. The most common approach to estimating emissions is to select an emission factor associated with a process and combine it with the activity (thruput) of the operations. This amount is adjusted by the control efficiency of the devices attached to the process. The final product is an estimate of pollutant emitted to the atmosphere. Actual emissions are calculated by:

$$\text{Actual emissions} = (\text{emission factor}) * (\text{activity data}) * (1 - \text{control efficiency}) \qquad (7)$$

There are several inaccuracies associated with this approach. Even though the precision of the emission factor or activity estimate may be poor, there is usually no quantifiable bias associated with these values. However, because of operational process upsets, down time of the control device, and maintenance of the control equipment, overall control efficiency of the devices attached to the process is not as great as stated by the manufacturers. This introduces a bias into the emission estimating process that is known qualitatively, but is not accounted for in the inventory.

Equation 7 assumes there is no bias in the emission factor or activity data and that the control device operates at 100 percent of its design efficiency all the time the process is running. To reflect reality, control efficiency should be adjusted for process upsets and control device downtime. Equation 7 then becomes:

$$\text{Actual emissions} = (\text{emission factor})_{\text{unctl}} * (\text{activity data}) * (1 - \text{control efficiency} * \text{OAF}) \qquad (8)$$

$$\text{where: OAF} = 1 - \frac{\text{Tons by-passing control device (t/y)}}{[\text{Tons collected (t/y)}] + [\text{Tons by-passing control device (t/y)}]}$$

The OAF is determined by examining operating records for a control device or family of devices. The amount of time it is operating, the number of process upsets, and the quantity of pollutant that bypasses the control device during these periods can be used to create the OAF.

Recently, some emission rates are being combined with process control efficiencies to form an emission factor that consists of a process-control device combination. Equation 8a is used when the emission factor incorporates control efficiency.

$$\text{Actual emissions} = (\text{emission factor})_{\text{ctl}} * (\text{activity data}) * (1/\text{CE} - \text{OAF}) \qquad (8a)$$

Summary

The emission inventory community has been using RE for almost a decade. Even though the term has been used interchangeably in totally different applications, the distinctions have been poorly understood. New terminology proposed in this paper should correct this problem. The PCI measures the degree to which a rule is being implemented (by measuring the amount of actual reduction and comparing it to the expected reduction). It is based on historical results from past rule implementation efforts or from recent surveys that indicate the degree of compliance to be expected. The PCI compensates for the failure of people to fully implement a rule.

The OAF is a function of control equipment efficiency, the adequacy of equipment maintenance, equipment reliability, and the stability of a process. This information is available from records maintained at each facility. The OAF compensates for the failure of equipment to perform at its stated capacity.

Next Steps

- determine how this proposed approach affects existing data
- determine how existing guidance must be changed to reflect new approach
- decide what to do about previously reported data that has RE applied
- develop new guidance explaining use of PCI and OAF.

References

(1) Federal Register, Vol 52, No. 226, Tuesday, November 24, 1987, p45059

(2) Federal Register, Vol 57, No. 74, Part III, Thursday, April 16, 1992

(3) “Guidelines for Estimating and Applying Rule Effectiveness for ozone/CO State Implementation Plan Base year Inventories”, November 1992, EPA-452/R-92-010

(4) ”Rule Effectiveness Guidance: Integration of Inventory, Compliance, and Assessment Applications”, January 1994, EPA-452/4-94-001

(5) “Developing Present and Future Year Emissions Inventories Using Rule Effectiveness Factors”, presented at the International Conference and course, Emission Inventory Issues, Durham, NC, October 1992.

(6) “Emission Inventories and Proper Use of Rule Effectiveness”, http://www.epa.gov/ttn/chief/eiip/pointsrc.htm, draft report, October 1998.

APPENDIX B

EIIP'S TECHNICAL PAPER *EMISSION INVENTORIES AND PROPER USE OF RULE EFFECTIVENESS*

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EMISSION INVENTORIES AND PROPER USE OF RULE EFFECTIVENESS

Prepared by:

Emission Inventory Improvement Program
Point Sources Committee

September 23, 1998

PURPOSE

The purpose of this document is to discuss Rule Effectiveness (RE) and explore its applicability in a base year and a projected year emission inventory development process. This document also presents how RE can be built into an electronic database to develop inventories.

BACKGROUND

Emission inventories for criteria pollutants are required by state and federal statutes. They have many uses including developing control strategies to reduce emissions. Inventory data (current and projected) are also used in air quality models that attempt to relate emissions in the inventory to the ground-level pollutant concentrations recorded by instruments. To design effective control strategies, inventories showing actual emissions for the period of concern are required.

Over the years, inventories have shown emission reductions due to adopted rules (regulations) but air quality measurement data have not shown corresponding reductions in pollutant levels. Therefore, the U.S. Environmental Protection Agency (EPA) concluded that the calculated emissions reported in inventories were too low because the level of control efficiencies applied to the calculations was too high.

EPA assumed that the emission inventory preparers were using the level of controls specified by the rules and were not giving any consideration to less than full compliance. EPA thus developed a solution to lower the level of control by multiplying the control efficiency by a correction factor called Rule Effectiveness (RE). When no better information was available, EPA guidance suggested a default 80% RE value. This guidance has been implemented inconsistently by the states with unintended consequences.

Inventories reporting actual emissions are in fact only estimates of those emissions. EPA had concerns that the emission factors for pollutant sources and abatement devices provided in AP-42 underestimate emissions because these factors do not account for equipment malfunctions and abatement device downtime. Emissions could also be underestimated due to ignorance of rules or circumvention of controls, process upsets, spills, and other day-to-day operating parameters. These parameters can significantly affect the estimates of actual emissions. Many of these parameters apply to all pollutant sources and not only to sources subject to rules. RE can not and should not be applied to uncontrolled sources. Therefore, the use of correction factors to account for these problems and unknown parameters in the emission calculation procedure is very appealing. There is a need for guidance to improve emission calculation procedures to account for the parameters mentioned above. These issues will be addressed in another document titled *Effects of Source Operational Problems*, being prepared by the Point Sources Committee of the Emission Inventory Improvement Program (EIIP).

However, RE plays an important role in emission inventory and rule development. Rules are adopted to reduce emissions by specified amounts. RE is a function of actual emissions and the emissions estimates calculated using limits specified in a rule. Actual estimated emissions should take into account various operational problems such as equipment malfunction and abatement device downtime. RE measures how well emission controls called for by a rule are being achieved in the real world. Therefore, RE measures the degree to which the actual estimated emissions approaches the expected emissions called for by a rule. If the actual estimated emissions are equal to the expected emissions based on rule limits specified in a rule, then the effectiveness for that rule is 100%. If the actual estimated emissions are higher than the expected emissions based on rule limits, then the RE is less than 100%. If the actual estimated emissions are lower than the expected emissions based on rule limits, then the RE is greater than 100% (i.e., over compliance).

BASE YEAR EMISSION CALCULATIONS AND RE

The purpose of adopting and implementing rules is to reduce emissions. Emissions can be reduced by lowering a source’s activity, or the emission factor that represents that activity, or adding control devices. Permit conditions are sometimes imposed on a facility to lower or limit activity levels. There are two ways to lower emission factors (final rate of emissions) for a source:

- The processes can be modified to inherently low emissions rates; or,
- Pollution control equipment can be incorporated into the process.

In either case, emissions estimated before and after regulatory changes will show actual emission changes due to controls. The actual estimated emissions when compared with the expected emissions based on rule limits will give the RE.

The final controlled emission factor = uncontrolled emission factor x (1 - % reduction specified in the rule/100 x % RE /100)

Actual estimated emissions from sources subject to a rule can be calculated using two different methods. The first method uses actual data, and the second uses values stated in the rule(s) to estimate the actual emissions after rule implementation. These two methods will be described in detail in the subsections below and will show that when actual data are used, RE is not part of the emission calculations. When actual data are not available, estimated RE is used to calculate emissions.

Estimating Emissions Using Actual Data: Emission calculations from point sources usually fall in this category because detailed source and throughput information is usually collected and stored in a database. One emissions calculation procedure for a process is to multiply the activity (throughput) by an emission factor, and by the control equipment efficiency if control equipment is used. The emissions can be updated by updating throughput, as long as control equipment has not changed. Emission factors are obtained from source tests, AP-42, engineering estimates, or other sources. If continuous monitoring is available, emission factors can be calculated and stored in the database. Source-specific emission factors, when available, are preferred to generalized factors. Emission factors are not derived from any rule, rather they represent best estimates of actual factors for the source and should account for any operational problems. The selection of emission factors for use in an inventory should be left to the estimator’s judgment. Guidance in selecting emission factors is also available in EIIP documents where preferred emission estimation methods are recommended.

The control equipment efficiency used can be either specific or general. The control efficiency for actual emission calculations should be based on design specifications, testing, or estimated values for the equipment. The control efficiency selected should be adjusted to reflect actual conditions. If a given type of equipment has problems operating continuously, design values should be adjusted to reflect the problems. This gives the estimated actual emissions. When a general control efficiency is used, it is not based on the design specification but is a “best judgment” value that takes into account deterioration, maintenance needs, and other day-to-day issues encountered. Emissions thus calculated are not the same as emissions estimated using values in rules, but represent actual estimates for emission inventories.

Emissions from some area source categories also can be calculated using actual data. For example, using the EIIP preferred method, emissions from the architectural coatings category can be calculated by obtaining the coating usage data and the solvent content for each type of coating by surveys.

Note that RE is not used in emission calculation procedures using actual data. RE can be calculated from the actual estimated emissions and emissions calculated using limits in the rule. For rulemaking or for emission inventories (by source categories), there may be some value in estimating RE for individual sources; emissions from all sources subject to a rule should be aggregated by categories. The composite emission factor obtained by dividing the total actual emissions by the total throughput when compared with the rate of emissions specified in the rule will give the estimated RE. Consistent units must be used in these calculations and comparisons. RE can also be obtained using the emissions instead of the emission factors as discussed above.

Estimating Emissions Using Information from Rules: Emissions from area source categories are sometimes calculated using emission rate data from rules. Emissions for area sources are usually calculated by categories instead of by individual sources and are based on estimated emission factors and activity data. Activity levels are usually derived from available surrogate data, and the emission factors selected generally will change over the years. If there are changes in a category (e.g., new technology or operational changes), then the emission factors should be reevaluated. The activity usually changes with changes in the surrogates used.

When a rule is adopted and implemented, new emission factors to account for the controls are usually not developed. Lower emissions are accounted for in the control efficiency. It is usually not easy to determine the percentage of control called for by a rule, but the emission inventory estimators must estimate the level of controls called for by a rule. It is important to remember that the emissions are estimated for a category and not for individual sources.

For example, emissions from underground gasoline storage tanks can be calculated by adjusting the uncontrolled emission factor by the percent control specified in the rule and the estimated RE. This is not the best or the preferred method, but is commonly used. This method can be used to calculate emissions from, for example, the architectural coatings category because the final controlled emission factor(s) are estimated using controls specified in the rule instead of obtaining actual emission factors independently.

EMISSION PROJECTIONS

The estimated RE value obtained in the base year calculations can be used to develop a future year RE value. The base year inventory, as discussed above, may or may not include RE in emission calculations. To prepare projections for categories subject to rules with future implementation dates, the estimated net controls for the rule (controls specified in the rules and the estimated RE) are required. Some sources in the category may comply before the rule's specified implementation date and others may comply after the implementation date. Also, as time passes, more sources comply and the RE increases. Therefore, changing the RE by specific dates will result in better estimates for future year emissions. Future year emissions for categories subject to rules are calculated by the following equation:

Future year emissions = base year emissions x growth factors x control factors

The control factors represent the net controls, based on the controls specified in the rule and the anticipated RE. Similarly, historical emissions can be recalculated using the above equation.

EMISSION INVENTORY SYSTEM

An emission calculation system using RE data is shown in this section. This system works for calculating future and historical emissions for all point and area sources and also for base year calculations for area source categories. In this system, two separate files are used to estimate the net emission factors for any given year, an emission factor file and an emission control file. Only the area source categories will have emission factors in the emission factor file, and only the categories subject to rules will have control information in the emission control file as described below.

Emission Factor File: Data in this file are organized by categories and are only for area sources. Categories with major point sources will not have any entry in this file because their emissions are calculated source-by-source using actual data. Only the uncontrolled emission factors for area sources (with known generation dates) are kept in this file. Changes in emission factors over the years due to reasons other than rulemaking (e.g., changes in technology) should be reflected in this file. Therefore, more than one record can exist for a given category with different emission factors and their corresponding effective dates.

Emission Control File: Data in this file are for categories subject to a rule. This file contains data for point as well as area source categories. Each record will have a unique identification number for each category, the percentage of reduction of the pollutant (maximum achievable) specified by the rule, and the percent RE (% RE) as shown in Table 1. A category can have more than one record to represent different dates with changing % RE as shown in Table 1, as well as to represent different geographic areas of rule applicability.

TABLE 1
EXAMPLE OF EMISSION CONTROL FILE

Category Identification	% Control	Date	Pollutant	% RE
10	60	Jan 1, 1998	VOC	20
10	60	Jan 1, 1999	VOC	70
10	60	Jan 1, 2000	VOC	95

This file can be expanded to store additional information about the rule if desired (date of adoption, rule description, etc.). The example in Table 1 is for category identification number 10 that is subject to a rule requiring 60% VOC control. The percent RE improves from 20% to 95% over 3 years and assumes there is no rule requiring control prior to January 1, 1998.

Emission Calculation: For the emission calculation procedure, the latest emission factor should be selected and used for all years after this date except when data in the emission control file exist. In such a case, the net emission factor is calculated by multiplying the emission factor(s) from the emission factor file and the control(s) and the effectiveness from the emission control file. With this method, past and future emissions can be calculated if throughput data (or growth rates) are available for various years.

Base year emissions for area source categories are similarly calculated by multiplying the base year throughput with the appropriate emission factors from the same files. A simple system of files can be set up for the data requirements stated above. For a more elaborate system, refer to the paper *Developing Present and Future Emissions Inventories Using Rule Effectiveness Factors* by T. Mangat, T. Story, and T. Perardi. This paper was presented at the October 1992 Emission Inventory Conference sponsored by the Air & Waste Management Association in Durham, North Carolina.

Rule Penetration: When a rule for a source category is adopted with a stated level of control, some sources may be exempted or may have limits set at higher levels (lower level of control). This can lower the overall control achieved for a source category subject to a rule. Frequently, some sources in a category will not comply or will be late in complying with the limits in the rule. All of these factors should be considered when determining the RE for a source category. It simplifies calculations if the maximum control achieved from the rule is kept constant and only the RE is varied to indicate the effectiveness of controls. The net control for the source category is then obtained by multiplying the percentage of control and the RE. There is no need to store a separate rule penetration factor in the database.

RECOMMENDATIONS

It is desirable to know the level of controls and the RE being achieved from rules. If the RE is determined and found to be lower than 100%, measures such as stepping up enforcement can be taken to correct the deficiencies. Knowing the actual controls (controls x RE) achieved in the base year will help in estimating future controls from the rule. Similarly, base year level of control when backtracked correctly should yield historical control information. RE should be tracked at a source category level. When base year emissions are estimated using actual data, RE and the controls specified in the rules are not required for calculating actual estimated emissions. Actual estimated emissions can also be directly calculated from source test data or by mass balance. To calculate actual estimated emissions from point sources, consideration should be given to uncertainties associated with various factors that affect emissions. Many area source categories may use controls specified in rules and the RE to calculate base year emissions.

For forecasting emissions, all source categories subject to a rule should track the controls specified by the rule and the RE. The estimated RE should account for rule penetration if the source category contains sources exempt from the rule. This adjustment to RE to account for rule penetration is not needed if the exempt sources are grouped under a different source category showing no controls.

Can RE be used in calculating emission inventories? The answer is yes, and when used correctly, it can help in calculating actual estimated emissions--especially in forecasts and backcasts. Is it important to know the RE for a rule? The answer is yes, even if it is difficult to calculate or estimate. To evaluate the effects of a promulgated rule, emission controls specified by the rule and the RE should be estimated.

APPENDIX C

CROSS REFERENCE OF AIR POLLUTION CONTROL DEVICE NAMES

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AIR POLLUTION CONTROL DEVICE NAMES

Some control devices are known and referred to by more than one name. For example, a fabric filter is also referred to as a baghouse. To assist readers in correlating the name of a specific control device of interest where the name is not one of those used in this document to the name of the device as used in this document, a list of cross reference names is provided in the following table. The Control Device column in the table presents the different names used for specific control devices. For each name in the Control Device column, the name for the device that is used in this document is provided on the same row in the Cross Reference column. For example, where “baghouse” is presented in the Control Device column, the Cross Reference column lists “fabric filter”, which is the name used in this document.

APPENDIX C

CROSS REFERENCE OF AIR POLLUTION CONTROL DEVICE NAMES

Control Device	Cross Reference Name
Absorbers (Scrubbers)	Wet acid gas scrubber
Absorption	Wet acid gas scrubber
Ammonia Injection	Selective Noncatalytic Reduction (SNCR)
Annular Orifice Venturi Scrubber	Wet PM scrubber
Baghouse	Fabric filter
Butadiene Adsorber	Carbon adsorber
Catalytic Afterburners	Catalytic Incinerator
Centrifugal Collector	Mechanical Collector
Centrifugal Cyclone	Mechanical Collector
Cyclone/Fabric Filter	Mechanical Collector/Fabric Filter
Cyclones	Mechanical Collector
Dry Cyclones	Mechanical Collector
Dry Scrubbers	Spray Dryer Absorber
Dry Sorbent Injection	Dry Injection
Dry Sorbent Scrubber	Spray Dryer Absorber
Dual Cyclones	Mechanical Collector
Duct Injection	Dry Injection
ESP	Electrostatic Precipitator
FGR	Flue Gas Recirculation
Fuel Cell Incineration	Thermal Incinerator
Impingement Scrubbers	Wet PM Scrubber
Incineration	Thermal Incinerator
LEA	Low Excess Air
LNB	Low NO_x Burner (LNB)
Multiple cyclones in series	Mechanical Collector
Multiple cyclones	Mechanical Collector
Multiclones	Mechanical Collector
NSCR	Nonselective Catalytic Reduction (NSCR)
OFA	Over-Fire Air
Reburn	Natural Gas Burners/Reburn
SCR	Selective Catalytic Reduction (SCR)
SNCR	Selective Noncatalytic Reduction (SNCR)
Sodium Scrubbers	Spray Dryer Absorber
SOFA	Staged Overfired Air

APPENDIX C

CONTINUED

Control Device	**Cross Reference Name**
Spray Drying	Spray Dryer Absorber
Thermal Afterburners	Thermal Incinerator
Thermal Oxidation	Thermal Incinerator
Venturi Scrubbers	Wet PM Scrubber
Wet FGD	Wet Acid Gas Scrubber
Wet Scrubbers	Wet Acid Gas Scrubber, or Wet PM Scrubber
Urea Injection	Selection Noncatalytic Reduction (SNCR)
Staged Combustion for Gas Turbines	Dry-Low NO_x (DLN), Dry-Low Emissions (DLE), or SoLo NO_x

APPENDIX D

DATA COMPILATION FOR SECTION 3

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DESCRIPTION OF HOW THE DATA WERE COMPILED

D.1 CONTROL EFFICIENCIES TABLE

- Individual table included for each pollutant of interest-CO, NO_x, PM, SO_x, VOC.

- Tables present control efficiencies (CE) for selected control devices for each unique combination of emission source and control device reported in the references. Where one or more references report an average CE, or CE range, for the same combination of emission source and control device, the references are examined to determine which one provides the best quality data and the data from that reference are selected and shown in the table. (The “best” data are determined using professional experience and judgment.)

- Each pollutant table contains columns that show an average CE and CE range for each unique combination of emission source and control device for which data are provided in the references.

  - The emission source is identified in the Process and Operation columns. For example, where a reference reported a CE for a boiler burning coal, “Fuel Combustion-Coal” is shown in the Process column and “Boiler” is shown in the Operation column.

  - A single column (Control Device Type) is used to identify the type of control device. The description of the control device provided in the reference was used to assign a control device type.

  - The average CE is presented in the column labeled Average CE (%). The reference citation for the average CE is shown in the column to the right labeled Reference. Two columns are used to show a range with the lower value on the left in the column labeled CE Range (%) Minimum and the upper value on the right in the column labeled Maximum. The reference citation for the range is shown in the column to the right labeled Reference. It should be noted that the average CE and CE range could be from two separate references. Where data were not available, the column is empty.

  - Where only a minimum value for the CE was available from the references, the value is presented in the Minimum column. The Maximum column is left empty. Where only a maximum value was available, the value is presented in the Maximum column and the Minimum column is left empty.

  - Where one reference provided only one value of a range (minimum <u>or</u> maximum) and a second reference provided both values (minimum <u>and</u> maximum), the data from the second reference are presented in the table. The data from the first reference were not used.

D.2 DATA FOR CONTROL DEVICES NOT EVALUATED

- Table D-1 presents control efficiencies (CE) reported in the references for control devices not evaluated in this document.

- Individual table included for each pollutant of interest-CO, NO_x, PM, SO_x, VOC.

  - Each pollutant table contains columns that show an average CE and CE range by emission source and control device for which data are provided in the references.

  - The reference citation for each row of data in the table is indicated in the Reference column.

  - The emission source is identified in the Process and Operation columns. For example, where a reference reported a CE for a boiler burning coal, “Fuel Combustion-Coal” is shown in the Process column and “Boiler” is shown in the Operation column.

  - The description of the control device provided in the reference is included in the Control Device Description column.

  - The description of the control device provided in the reference was used to assign a control device type which appears in the Control Device Type Column.

  - Where a reference provided an average CE, the CE is shown in the Average CE (%) column. Where a reference provided a minimum or maximum CE, or both, they are shown in the CE Range (%) Minimum and Maximum columns, respectively. Because the data in the table are “as entered” and have not been evaluated, an Average CE and a range CE obtained from the same reference will appear in two separate rows.

TABLE D-1

CONTROL EFFICIENCIES FOR CONTROL DEVICES NOT EVALUATED IN THIS DOCUMENT

Pollutant	Process	Operation	Control Device Type	Average CE (%)[a]	Reference	CE Range (%) Minimum Value	CE Range (%) Maximum Value	Reference
CO	Wood Industry	Dryer/Press Exhaust	Biofilter			30	50	EPA, 1995
NO_X	Fuel Combustion- Coal	Boiler	Limestone Injection Multi-stage Burner			50	60	EPA, 1992b
NO_X	Fuel Combustion- Coal	Boiler	WAS-SNOX				90	EPA, 1992b
NO_X	Fuel Combustion- Coal	Boiler	GR-SI				70	EPA, 1992b
NO_X	Petroleum Industry	Process Heaters	Natural Air Lances			10	20	EPA, 1992b
NO_X	Petroleum Industry	Process Heaters	Forced Air Lances			50	60	EPA, 1992b
NO_X	Wood Industry	Dryer/Press Exhaust	Biofilter			80	95	EPA, 1995
PM	Aluminum Industry	Baking Furnaces	Fabric Filter Wth Reduction Cell				99	EPA, 1995
PM	Fuel Combustion- Wood	Boiler	Granular-bed Moving Filter			90	95	AWMA, 1992
PM	Fuel Combustion- Wood	Boiler	Granular-bed Moving Filter with Electrostatic Precipitator			98	99.2	AWMA, 1992
PM	Fuel Combustion- Wood	Boiler	Gravel Bed Filter	95	EPA, 1995			

TABLE D-1

CONTROL EFFICIENCIES FOR CONTROL DEVICE NOT EVALUATED IN THIS DOCUMENT (CONTINUED)

Pollutant	Process	Operation	Control Device Type	Average CE (%)[a]	Reference	CE Range (%)		Reference
						Minimum Value	Maximum Value	
PM	Fuel Combustion- Wood	Boiler	Gravel Bed Filter	95	EPA, 1995			
PM	Fuel Combustion- Wood	Boiler	Gravel Bed Filter	95	AWMA, 1992			
PM	General	General	Core Separator			95	98	EPA, 1998
PM	Metallurgical Industry	Waste Heate Boiler	Tubular Cooler			70	80	AWMA, 1992
SO_X	Fuel Combustion- Coal	Boiler	Duct Injection			25	>50	AWMA, 1992
SO_X	Fuel Combustion- Coal	Boiler	Furnace Injection			25	50	AWMA, 1992
SO_X	Fuel Combustion- Coal	Boiler	Limestone Injection Multi-stage Burner			50	60	EPA, 1992b
SO_X	Fuel Combustion-Coal	Boiler	NOXSO	90	EPA, 1992b			
SO_X	Fuel Combustion- Coal	Boiler	WAS-SNOX	95	EPA, 1992b			
SO_X	Fuel Combustion- Oil	Boiler	Duct Injection			25	>50	AWMA, 1992
SO_X	Fuel Combustion- Oil	Boiler	Furnace Injection			25	50	AWMA, 1992
SO_X	Metallurgical Industry	Lead Smelters	DMA Absorber			92	95	AWMA, 1992
VOC	Aluminum Industry	Baking Furnaces	Fabric Filter with Reduction Cell				99	EPA, 1995
VOC	Chemical Manufacturing	SOCMI Reactor	Condenser			50	95	EPA, 1992a

TABLE D-1

CONTROL EFFICIENCIES FOR CONTROL DEVICES NOT EVALUATED IN THIS DOCUMENT (CONTINUED)

						CE Range (%)		
Pollutant	**Process**	**Operation**	**Control Device Type**	**Average CE (%)[a]**	**Reference**	**Minimum Value**	**Maximum Value**	**Reference**
VOC	Degreasing- Cold Cleaner	General	Hot Vapor Recycle			62	69	AWMA, 1992
VOC	Degreasing- In-line Cleaner	General	Above-Freezing Freeboard Refrigeration			61		AWMA, 1992
VOC	Degreasing- Open Top Vapor Cleaner	Idling Losses	Below-Freezing Freeboard Refrigeration			11	58	AWMA, 1992
VOC	Degreasing- Open Top Vapor Cleaner	Idling Losses	Increased Freeboard Ratio			27	47	AWMA, 1992
VOC	Degreasing- Open Top Vapor Cleaner	Working Losses	Above-Freezing Freeboard Refrigeration			18	50	AWMA, 1992
VOC	Degreasing- Open Top Vapor Cleaner	Working Losses	Below-Freezing Freeboard Refrigeration			26	54	AWMA, 1992
VOC	Degreasing- Open Top Vapor Cleaner	Working Losses	Increased Freeboard Ratio			25		AWMA, 1992
VOC	Degreasing- Open Top Vapor Cleaner	Working Losses	Refrigerated Primary Condenser			18	52	AWMA, 1992
VOC	Fabric Coating	General	Inert Gas Condensation System	99	EPA, 1992a			
VOC	Food Industry	Fermentor	Scrubber, Wet with Biofilter			90		EPA, 1995
VOC	Food Industry	Smokehouses	Scrubber, Vortex	51	EPA, 1995			
VOC	Gasoline Marketing	Loading	Submerged Filling	60	AWMA, 1992			
VOC	Gasoline Marketing	Service Stations	Vapor Balancing Stage I	90	AWMA, 1992			AWMA, 1992
VOC	Gasoline Marketing	Service Stations	Vapor Balancing Stage II			95		AWMA, 1992

TABLE D-1

CONTROL EFFICIENCIES FOR CONTROL DEVICES NOT EVALUATED IN THIS DOCUMENT (CONTINUED)

Pollutant	Process	Operation	Control Device Type	Average CE (%)[a]	Reference	CE Range (%) Minimum Value	CE Range (%) Maximum Value	Reference
VOC	General	General	Condenser	90	EPA, 1991	50	95	EPA, 1992a
VOC	General	Natural Gas Processing	Vapor Recovery				98	EPA, 1992a
VOC	Magnetic Tape Manufacture	Drying Ovens	Condenser	95	AWMA, 1992			
VOC	Surface Coating	Polymeric Coating	Vapor Recovery	95	AWMA, 1992			
VOC	Surface Coating	Vinyl Coating/Primer	Vapor Recovery			90		EPA, 1992a
VOC	Wood Industry	Dryer/Press Exhaust	Biofilter			70	90	EPA, 1995

APPENDIX E

EXAMPLE CALCULATIONS

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Example E-1--Coke and Coal Fired Boilers

For this example, consider a coal-fired boiler that operates as follows:

Throughput:	1,764 MMBTU/hr
Operating Hours:	8,500 hr/yr
Permitted emissions:	0.03 lb particulate/MMBTU
Control Device:	Electrostatic precipitator
Assumed CE:	99 percent (from Table 12.3-6)

If this process and its associated control equipment operated exactly as designed for the entire 8,500 hr/yr, the expected emissions would be:

expected annual
particulate emissions = 1,764 MMBTU/hr x 8,500 hrs/yr x 0.03 lb particulate/MMBTU
= ~450,000 lbs/yr
= ~225 tons/yr

However, low voltage or other malfunctions might cause the ESP to occasionally operate at 95 percent efficiency rather than 99 percent efficiency. During such events, the emission rate would be 0.12 lb particulate/MMBTU (four times the “normal” emission rate of 0.03 lb particulate/MMBTU). If these anomalous conditions occurred during 5 percent of the total operating hours (i.e., 425 of the 8,500 hrs per year) for the plant, annual particulate emissions would be:

actual annual
particulate emissions = 1,764 MMBTU/hr x (8,500 hrs/yr x 95%) x 0.03 lb/MMBTU
+ 1,764 MMBTU/hr x (8,500 hrs/yr x 5%) x 0.12 lb/MMBTU
= 517,293
= 258 tpy

Thus, in this example, a 4 percent reduction in ESP efficiency for 5 percent of the operating time would increase actual annual particulate emissions by 33 tpy (20 percent) over the permitted amount. If the state’s emission inventory estimate for this facility is based only on the permitted figures, the 33 tpy (20 percent) actual increase for this facility would be missed.

Example E-2--Wood Products Dryer/Press

For this example, consider a wood products dryer/press that operates as follows:

Operating schedule: 7,920 hr/yr
Process exhaust flow rate: 8,000 dscf/min
Permitted emissions: 0.01 gr/dscf
Control Device: Fabric filter

Permitted emissions: 27.4 lb/hr VOC (based on NSPS)
Assumed CE: 94 percent wet ESP and thermal oxidizer,

If this process and its associated control equipment meet the emission limits when operated normally and the process and control equipment operate normally for the entire 7,920 hr/year, emissions would be:

Expected annual PM_{10} emissions = 0.01 gr/dscf x 8,000 dscf/min x 60 min/hr x 1 lb/700 0 gr
= 0.686 lb/hr
= 0.686 lb/hr x 7920 hr/yr
= 5430 lb/yr
= 2.71 tpy

Expected annual VOC emissions = 27.4 lb/hr x 7,920 hrs/yr
= 217,008 lb/yr
= 108.5 tpy

In this example, if the thermal oxidizer were to fail for 4 hours per month, resulting in a reduction from 94 percent efficiency to 50 percent efficiency for VOC, VOC emissions will increase by 113.3 tpy, or an increase of 4.4 percent over expected annual emissions.

Occasional bag wear and tear will cause the fabric filter to malfunction. The malfunction of a fabric filter is immediately apparent as it results in accumulation of particles in the vicinity of the device, as uncontrolled gas escapes through holes in the fabric. Emissions resulting from the malfunction can be estimated by collecting and weighing the amount of dust escaping through the filter.

APPENDIX F

EXAMPLE ANNUAL EMISSION INCREASES FOR VARIOUS SCENARIOS

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A general formula for calculating increases in annual emissions due to malfunctioning control devices is:

$$I = t_a \times (CE_n - CE_a) / (100\% - CE_n)$$

where:

I = Increase in annual emissions due to a malfunctioning control device (%)
CE_n = Normal control efficiency (%)
CE_a = Malfunction control efficiency (%) [note: use the actual control efficiency. Do not express as a percent of the normal control efficiency.]
t_a = Operating time under malfunction conditions (% of total hours)

The three examples in this appendix use the above formula to calculate annual emission increases for three hypothetical examples. In each example, we assume a specific malfunction efficiency (e.g., assume that a malfunctioning fabric filter operates at 97.5 percent efficiency) and show the annual emission increases that would result under different combinations of design efficiencies and percentage malfunction time.

EXAMPLE F-1: VERY HIGH DESIGN EFFICIENCY AND SLIGHT DECREASES IN ACTUAL EFFICIENCY RESULT IN SIGNIFICANT ANNUAL EMISSION INCREASES

Consider a hypothetical ESP that operates under 97.5 percent efficiency during a minor malfunction. Table F-1 shows the emission increases that would occur if the device operated under malfunction conditions from 1 to 10 percent of the time, and if the ESP was otherwise expected to operate at design efficiencies between 98 and 99.5 percent.

For example, if the control device design efficiency is 99.5 percent, and the control device operates under malfunction conditions (at 97.5 percent efficiency) for 5 percent of the time, the increased emissions due to the malfunction would add 20 percent to the expected annual emission. The data in Table F-1 are presented graphically in Figure F-1.

As you can see in the example of Table F-1, small decreases in the control percentage can result in large percentage increases in actual emissions if the design efficiency is high.

Table F-1. Percentage Increase Over Expected Annual Emissions for an ESP Operating at 97.5% Efficiency During Malfunction

Design Efficiency	Percentage Downtime									
	1%	2%	3%	4%	5%	6%	7%	8%	9%	10%
99.5%	4.0%	8.0%	12.0%	16.0%	20.0%	24.0%	28.0%	32.0%	36.0%	40.0%
99.0%	1.5%	3.0%	4.5%	6.0%	7.5%	9.0%	10.5%	12.0%	13.5%	15.0%
98.5%	0.7%	1.3%	2.0%	2.7%	3.3%	4.0%	4.7%	5.3%	6.0%	6.7%
98.0%	0.3%	0.5%	0.8%	1.0%	1.3%	1.5%	1.8%	2.0%	2.3%	2.5%

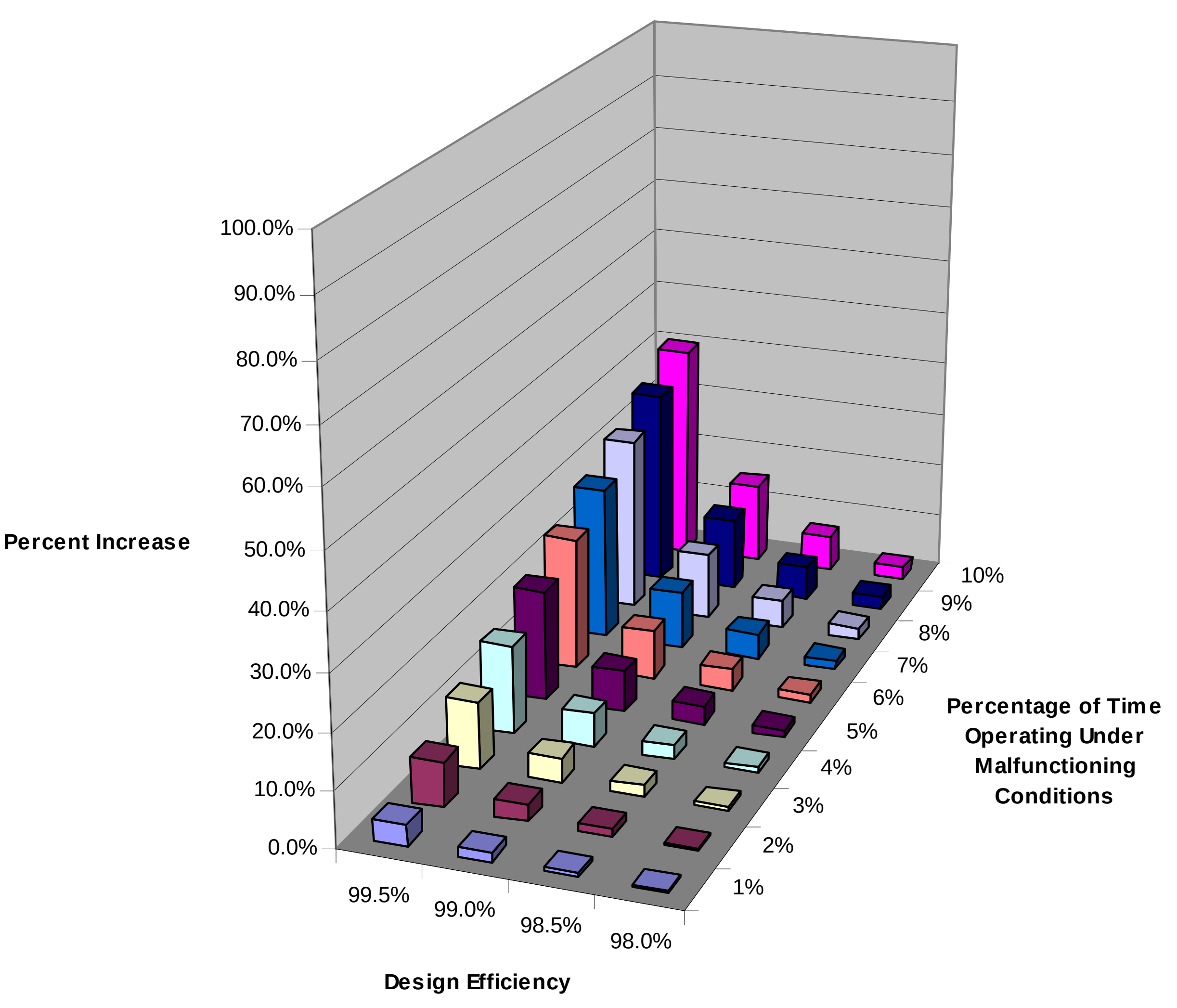

Figure F-1. Percent Increase in Actual Annual Emissions with Malfunction Efficiency at 97.5%

EXAMPLE F-2: LOW DESIGN EFFICIENCY AND LARGE DECREASES IN ACTUAL EFFICIENCY RESULT IN LESS SIGNIFICANT EMISSION INCREASES

In contrast to the case in Example F-1, emission changes are less significant if the design efficiency is low, as might be the case with a NO_x scrubber designed to operate at control efficiencies between 80 - 70 percent. If, for example, a NO_x scrubber with a design efficiency of 80 percent actually operated at 50 percent efficiency during malfunction conditions 5 percent of the year, actual annual emissions would only be 7.5 percent over the expected annual emissions. Table F-2 and Figure F-2 show the percentage increase for various scenarios in which the NO_x scrubber operates at 50 percent control efficiency during malfunction.

Table F-2. Percentage Increase Over Expected Actual Emissions for NO_x Scrubber Operating at 50% Efficiency During Malfunction

Design Efficiency	Percentage Downtime									
	1%	2%	3%	4%	5%	6%	7%	8%	9%	10%
80.0%	1.5%	3.0%	4.5%	6.0%	7.5%	9.0%	10.5%	12.0%	13.5%	15.0%
79.0%	1.4%	2.8%	4.1%	5.5%	6.9%	8.3%	9.7%	11.0%	12.4%	13.8%
78.0%	1.3%	2.5%	3.8%	5.1%	6.4%	7.6%	8.9%	10.2%	11.5%	12.7%
77.0%	1.2%	2.3%	3.5%	4.7%	5.9%	7.0%	8.2%	9.4%	10.6%	11.7%
76.0%	1.1%	2.2%	3.3%	4.3%	5.4%	6.5%	7.6%	8.7%	9.8%	10.8%
75.0%	1.0%	2.0%	3.0%	4.0%	5.0%	6.0%	7.0%	8.0%	9.0%	10.0%
74.0%	0.9%	1.8%	2.8%	3.7%	4.6%	5.5%	6.5%	7.4%	8.3%	9.2%
73.0%	0.9%	1.7%	2.6%	3.4%	4.3%	5.1%	6.0%	6.8%	7.7%	8.5%
72.0%	0.8%	1.6%	2.4%	3.1%	3.9%	4.7%	5.5%	6.3%	7.1%	7.9%
70.0%	0.7%	1.3%	2.0%	2.7%	3.3%	4.0%	4.7%	5.3%	6.0%	6.7%

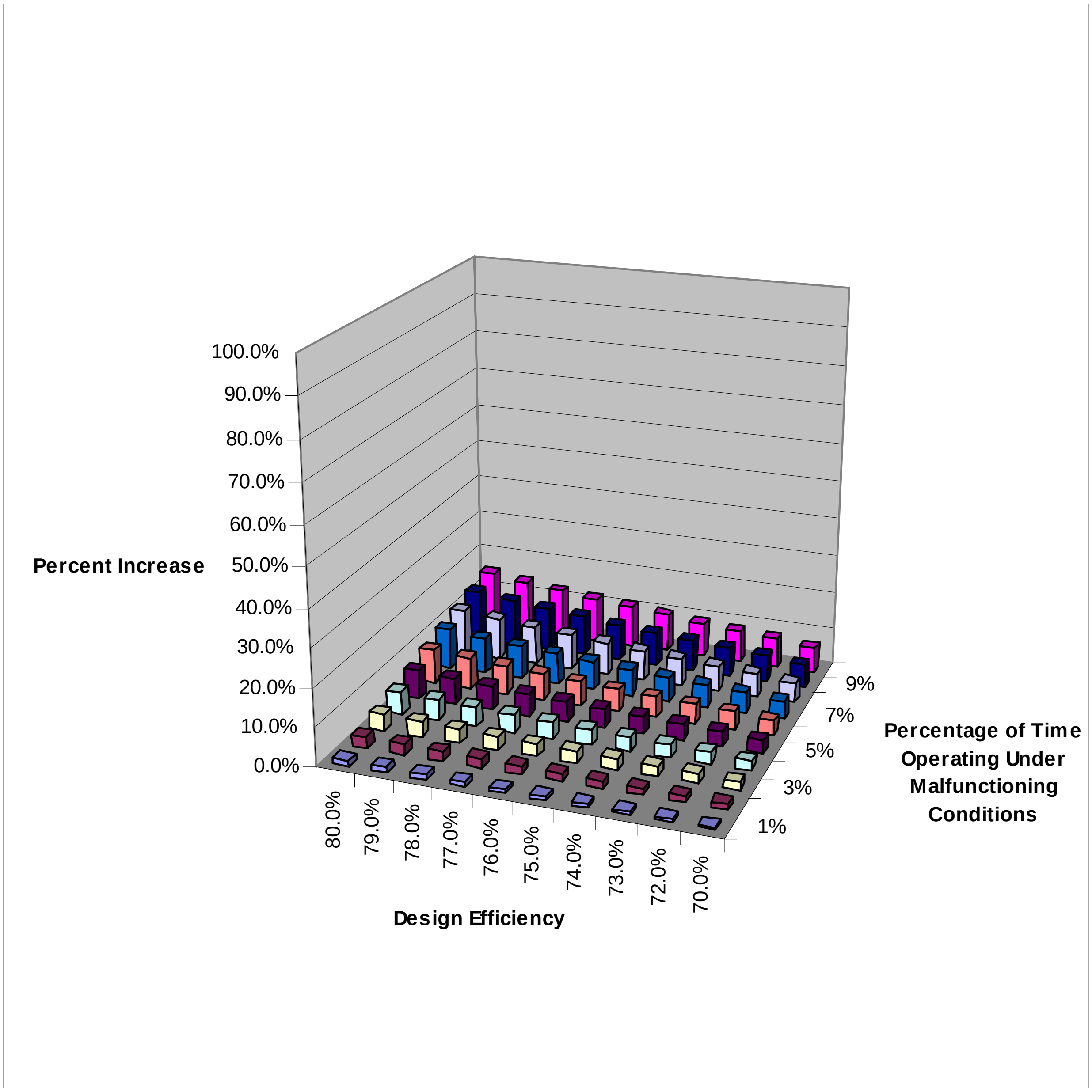

Figure F-2. Percentage Increase in Actual Annual Emissions with Malfunction Efficiency at 50%

EXAMPLE F-3: MODERATELY HIGH DESIGN EFFICIENCY AND LARGE DECREASES IN ACTUAL EFFICIENCY RESULT IN VERY HIGH INCREASES IN ACTUAL ANNUAL EMISSIONS

As would be expected, there will be very high increases in actual annual emissions if the design efficiency is high and the actual efficiency greatly decreases for even a short while. Failure of a VOC control system (e.g., due to flame out or pump failure) can result in large efficiency drops that may go undetected if the VOC is odorless or colorless, or if the stack does not vent near people. For example, if a malfunctioning control device operates at only 25 percent efficiency for 1 percent of the year, but is supposed to operate at 95 percent efficiency year round, the annual emissions will increase by 14 percent. If the control device is supposed to operate at 99 percent efficiency year round, the annual emissions will increase by 74 percent!

Table F-3 and Figure F-3 show the percentage increase for various scenarios in which a malfunctioning control device operates at only 25 percent control efficiency.

Table F-3. Percentage increase Over Expected Annual Emissions for VOC Adsorber Operating at 25% Efficiency During Malfunction

Design Efficiency	Percentage Downtime									
	1%	2%	3%	4%	5%	6%	7%	8%	9%	10%
99.0%	74.0%	148.0	222.0	296.0	370.0%	444.0%	518.0%	592.0%	666.0%	740.0%
98.0%	36.5%	73.0%	109.5	146.0	182.5%	219.0%	255.5%	292.0%	328.5%	365.0%
97.0%	24.0%	48.0%	72.0%	96.0%	120.0%	144.0%	168.0%	192.0%	216.0%	240.0%
96.0%	17.8%	35.5%	53.3%	71.0%	88.7%	106.5%	124.3%	142.0%	159.8%	177.5%
95.0%	14.0%	28.0%	42.0%	56.0%	70.0%	84.0%	98.0%	112.0%	126.0%	140.0%
94.0%	11.5%	23.0%	34.5%	46.0%	57.5%	69.0%	80.5%	92.0%	103.5%	115.0%
93.0%	9.7%	19.4%	29.1%	38.9%	48.6%	58.3%	68.0%	77.7%	87.4%	97.1%
92.0%	8.4%	16.8%	25.1%	33.5%	41.9%	50.3%	58.6%	67.0%	75.4%	83.8%
91.0%	7.3%	14.7%	22.0%	29.3%	36.7%	44.0%	51.3%	58.7%	66.0%	73.3%
90.0%	6.5%	13.0%	19.5%	26.0%	32.5%	39.0%	45.5%	52.0%	58.5%	65.0%

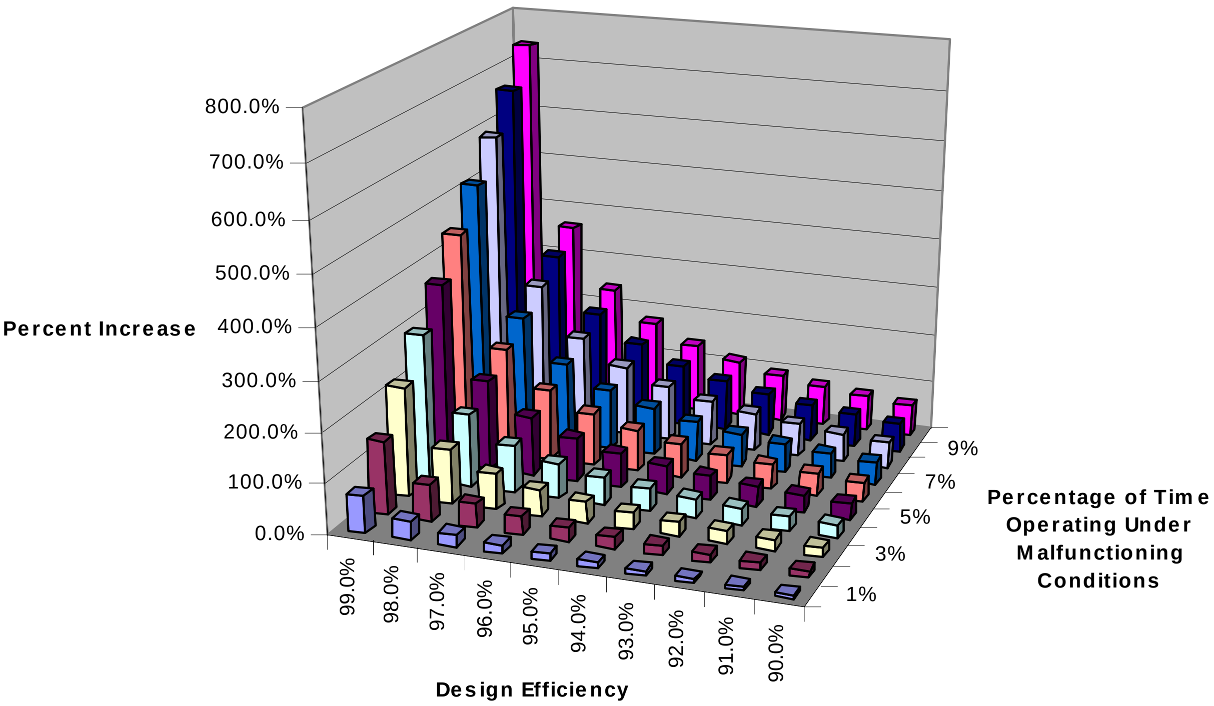

Figure F-3. Percentage Increase in Actual Annual Emissions with Malfunction Efficiency at 25%

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APPENDIX G

DATA SOURCES FOR SECTION 5

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Data Needed	Data Source	Comments
Target Control Level or Emission Rate	NSPS, MACT, NESHAP, or other Federal regulations State regulations Permit Conditions	Regulations and permit conditions may list the target control level or emission rate. These values may be included in the (RACT/BACT/LAER Clearinghouse) accessible via the EPA website.
	EIIP guidance	The EIIP guidance provides calculation methods and expected control levels for numerous source categories.
Actual Control Level of Emission Rates	NSPS, MACT, NESHAP, or other Federal regulations guidance on maximum downtime State regulations for maximum downtime Permit conditions for maximum downtime	Regulations and permit conditions may indicate maximum allowable downtimes or maximum allowable excess emissions that are below the target control rate but still within compliance with the rule.
	Quarterly CEM reports where required by Federal or state rules (e.g., for utility boilers)	Some sources (e.g., utility boilers) must file quarterly CEM reports with the state agency. Data in these reports might not make it to the emission inventory branch unless you specifically request them.
	EIIP guidance	The EIIP guidance provides calculation methods and expected control levels for numerous source categories.
	Facility reports for excess emissions	Facilities may file reports of excess emissions with state permitting or compliance staff, particularly if permit conditions require.
	State databases (e.g., DEERS in South Carolina) for tracking excess emissions	Some states (e.g., Texas and South Carolina) keep databases of excess emissions reported by facilities.
	State compliance or permitting staff	State compliance and permitting staff will be the best sources of information regarding the expected amount of downtime and the expected degree of reduced control.

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