UPDATE OF CONTROL EQUIPMENT DATA TO SUPPORT MPCA'S CONTROL EQUIPMENT RULE: FINAL REPORT

PECHAN

5528-B Hempstead Way
Springfield, VA 22151

703-813-6700 telephone
703-813-6729 facsimile

3622 Lyckan Parkway
Suite 2002
Durham, NC 27707

919-493-3144 telephone
919-493-3182 facsimile

P.O. Box 1345
El Dorado, CA 95623

530-295-2995 telephone
530-295-2999 facsimile

Prepared for:

Stuart Arkley
Minnesota Pollution Control Agency

Prepared by:

Stephen M. Roe
Ying K. Hsu
Maggie Ma
Holly C. Lindquist
E.H. Pechan & Associates, Inc.
P.O. Box 1345
El Dorado, CA 95623

June 2005

Pechan Report No. 05.06.00X/9446.000
CFMS No. A72995

CONTENTS

Page

ACRONYMS iv
I. INTRODUCTION 1
II. CONTROL EQUIPMENT DATABASE 3
III. SUPPORTING INFORMATION 5
APPENDIX A. DEVICE DESCRIPTIONS A-1
APPENDIX B. TAP LIST AND ASSOCIATED CATEGORIES B-1

TABLES

Page

Table I-1. Final Format for the Control Equipment Database 2
Table III-1. Sample Organic TAPs Grouped by Ease of Thermal Destruction 7

ACRONYMS

AIRS/FS	Aerometric Information Retrieval System/ Facility Subsystem
$Ca[OH]_2$	calcium hydroxide
CARB	California Air Resources Board
CAS	Chemical Abstracts Service
cfm	cubic feet per minute
cm	centimeter
CO	carbon monoxide
CO_2	carbon dioxide
CVOC	chlorinated volatile organic compound
EPA	U.S. Environmental Protection Agency
ESP	electrostatic precipitator
FGD	flue-gas desulfurization
GIT	gaseous inorganic TAP
g/m^3	grams per cubic meter
H_2SO_4	sulfuric acid
HCl	hydrochloric acid
HEPA	High Efficiency Particle Air
Hg	mercury
in.wg	inch water gauge
l/m^3	liters per cubic meter
lb	pound
LEL	lower explosive limit
MEK	methylethyl ketone
MMBtu	million British thermal unit
MPCA	Minnesota Pollution Control Agency
Na_2CO_3	sodium carbonate
NAAQS	National Ambient Air Quality Standards
NaOH	sodium hydroxide
NEDS	National Emissions Data System
NIF	National Inventory Format
NOx	oxides of nitrogen
NTE	non-total enclosure
Pechan	E.H. Pechan & Associates, Inc.
PM	particulate matter
PIT	particulate inorganic TAP
POT	particulate organic TAP
ppmv	parts per million by volume
SO_2	sulfur dioxide
SO_3	sulfur trioxide
SOx	sulfur oxide
TAP	toxic air pollutant
TE	total enclosure
TM	technical memorandum
TNMOG	total nonmethane organic gases

TSP	total suspended particulate
ULPA	Ultra Low Penetration Air
µm	micrometers
VOC	volatile organic compound
VOT	volatile organic TAP

I. INTRODUCTION

E.H. Pechan & Associates, Inc. (Pechan) was contracted by the Minnesota Pollution Control Agency (MPCA) to develop an air pollution control equipment database to support future revisions to MPCA's Control Equipment Rule (the Rule). The equipment covered in the database should be those most likely to be employed by facilities that would be affected by the Rule. These facilities generally exclude utilities and large industrial sources. Pechan reviewed the Rule and information provided by MPCA to develop a prioritized list of equipment types. A description of this work was provided in Technical Memorandum #1 (TM#1) to MPCA (Pechan, 2005).

In addition to developing a prioritized list of control equipment to be researched under this project, Pechan provided details in TM#1 on the contents and structure of the database to be developed under this project. Follow-up discussions with MPCA staff led to some changes in the data structure. The final structure is shown in Table 1 below. The data elements are described in more detail in Section II below.

The starting point for the development of the MPCA database was a similar database developed by Pechan for the California Air Resources Board (CARB) (Roe et al, 1998). Pechan researched new information to update the control efficiencies in the CARB database. A literature search and internet searches were conducted to gather the new information. Surveys of air pollution control equipment manufacturers and testing companies were also performed. Structural differences between the CARB and MPCA databases include the addition of fields to hold applicable EPA control device codes and estimates of "representative" control efficiencies (instead of just low and high efficiencies), monitoring parameters, and record-keeping requirements. Another difference was the addition of records to represent total enclosure (TE) or non-total enclosure (NTE) values. The difference in these two record types is that the NTE records incorporate an estimate of capture efficiency in the control efficiency values (this issue is further described in Section II).

Section III provides additional supporting information for the database. This includes the methods used to assign control efficiencies to the four toxic air pollutant (TAP) groups shown in the database. Appendix A to this report provides descriptions of the control equipment in the database. Appendix B provides a list of TAP species and their assignment to the four different TAP groups. The control database has been supplied to MPCA in Microsoft Excel format. Section IV provides a list of references (note that Appendix A has a separate list of references specific to the device descriptions).

Table I-1. Final Format for the Control Equipment Database

MPCA Code	CONTROL DEVICE/METHOD	TE/NTE	Applicable EPA Codes	Device Description	PM		
					Low	High	Rep.
501	Mechanically-aided Separator	TE	056, 113	056 (Dynamic Separator(Dry); 113 (Rotoclone)	30.0	99.0	64.5
501	Mechanically-aided Separator	NTE	056, 113	056 (Dynamic Separator(Dry); 113 (Rotoclone)	24.0	79.2	51.6

(continued)

PM10			PM2.5			SOx			NOx			CO			VOC		
Low	High	Rep.	Low	High	Rep.	Low	High	Rep.	Low	High	Rep.	Low	High	Rep.	Low	High	Rep.
0.0	10.0	5.0	0.0	5.0	2.5												
0.0	8.0	4.0	0.0	4.0	2.0												

(continued)

VOT			POT			PIT			GIT			Monitoring Parameter(s)	Record-keeping Requirements
Low	High	Rep.	Low	High	Rep.	Low	High	Rep.	Low	High	Rep.		
			0.0	10.0	5.0	0.0	10.0	5.0				**Gas stream velocity and or pressure drop**	Daily recording of gas stream velocity and/or pressure drop
			0.0	8.0	4.0	0.0	8.0	4.0				**Gas stream velocity and or pressure drop**	Daily recording of gas stream velocity and/or pressure drop

II. CONTROL EQUIPMENT DATABASE

This section provides a description of each element in the MPCA control equipment database. Information is provided for each data field:

- *MPCA Code*: this is a 3-digit code assigned to each type of control equipment. Previous discussions with MPCA staff indicated that there might not be a need for such a field and that only the applicable EPA codes were needed. We found that we had a need internally to assign a specific code to each equipment type for easier tracking purposes. This field could be deleted, if it serves no use to MPCA.

- *Control Device/Method:* this is a name for the equipment type. In some cases, there are synonyms or closely-related equipment types included in parentheses. We have tried to maintain consistency with the U.S. Environmental Protection Agency's (EPA's) control device names; however this is not possible in all cases (e.g., where certain equipment types are not included in EPA's table).

- *TE/NTE:* defines whether the record contains control efficiency data for total enclosure or non-total enclosure situations. NTE records incorporate an estimate of capture (collection) efficiency, while TE records do not. Our default capture efficiency was 80% for all pollutants. This default assumption is based on expert judgment as well as communications with an equipment testing organization (Sharp, 2005). In reality, the range of capture efficiency achieved in practice is expected to range from 50% or less to 98% or greater (e.g. sources subject to Maximum Achievable Control Technology standards or strict State standards). Large ranges in capture efficiency are expected even within the same control technology group (again depending on source type and the existence of strict control requirements). The 80% default is most applicable to recent control technology applications (e.g. within the last 10 years). Note that for certain control devices that are only associated with add-on (end of stack) applications (e.g. selective catalytic reduction), no NTE record is included.

- *Applicable EPA Codes:* these are the control equipment codes from EPA's database [i.e. as required for National Inventory Format (NIF) reporting]. Where possible, we adopted one of the available codes as the MPCA code above, but this was not always possible. Where the word "new" appears, the control technology is not in the EPA database, and we assigned a new 3-digit MPCA code in that field (beginning at 500). For the purposes of NIF reporting, MPCA staff should assign the code "099" for miscellaneous equipment for any MPCA codes starting with a 5.

- *Device Description:* this is the applicable device name from the EPA table.

- *PM (low, high, representative):* this is the particulate matter (PM) control efficiency estimates. These estimates are applicable to total suspended particulate (TSP) emissions. "Low" and "High" refer to the low and high ends of the range for each equipment type. The "Representative" value in most cases is set as the mid-point of the range. In the small number of cases where the mid-point was not selected, the basis for the representative values is provided in the Appendix A description. Similar to the capture efficiency issue described under TE/NTE above, the assignment of a typical or representative control efficiency is difficult. This is because many control technologies can be applied to a wide variety of sources and control requirements for any application can differ significantly (e.g. based on the requirements of federal or local control programs).

- *Remaining criteria pollutant efficiencies:* PM10 (particulate matter less than 10 microns); PM2.5 (particulate matter less than 2.5 microns); SOx (sulfur oxides); NOx (nitrogen oxides); CO (carbon monoxide); and VOC (volatile organic compounds); see the discussion in the preceding bullet on the meaning of "Low", "High", and "Representative".

- *VOT, POT, PIT, and GIT:* see Section III for a discussion of these TAP categories.

- *Monitoring Parameter(s):* this field contains a list of common monitoring parameters for each control technology. We bolded one or more of these parameters, as those that we felt were of primary importance to assure system performance. We commonly included language about the potential need for additional parameters based on equipment vendor specifications. Vendors will often provide guarantees of system performance, as long as the system is being operated within certain operating parameters. However, depending on the nature of the source, vendor-specified monitoring parameters can vary.

- *Record-Keeping Requirements:* these are the record-keeping requirements associated with the monitoring parameters above. Engineering judgment was used to assign a typical set of requirements; however these requirements could vary dramatically within the same technology group on different applications. For example, daily recording of combustion zone temperature might be appropriate for some applications of thermal oxidizers, while continuous recording would be appropriate in others (e.g. where important TAP emissions are an issue).

III. SUPPORTING INFORMATION

Appendix A contains the device descriptions for each of the controls in the database. The introductory material for each device includes the MPCA device code assigned and other applicable EPA control codes. As mentioned above, we assigned a single MPCA code to make it easier for us to track individual devices. The device descriptions also have sections on applicability, control efficiency (by pollutant, for each criteria pollutant), monitoring parameters, and record-keeping parameters (monitoring parameters of primary importance are bolded).

Data on control efficiencies achieved by various technologies for TAPs is sparse. Available data are often limited to one or a few TAP species, or are likely to be more source-specific than control technology-specific. Due to these issues, we decided to adopt the same methods that were applied in the CARB point source controls database development to establish reasonable control efficiencies for TAP species. For this project, we recognized that most of the existing controls that are applicable to TAPs were originally designed to control either PM or VOC. Therefore, we categorized each TAP as one of the following:

- *VOT* - (volatile organic toxics) these are carbon-containing TAPs that are typically encountered in a gaseous state;
- *POT* - (particulate organic toxics) these are carbon-containing TAPs that are typically encountered as a solid or liquid aerosol or attached to other PM;
- *PIT* - (particulate inorganic toxics) these are TAPs that do not contain a carbon atom and that exist as an aerosol or attached to other PM; and
- *GIT* - (gaseous inorganic toxics) these TAPs do not contain a carbon atom and exist as a gas.

Appendix B provides a list of TAP species and the assigned TAP category. The list includes both Clean Air Act hazardous air pollutants and some additional TAPs from the California list. The list is ordered by the non-hyphenated Chemical Abstracts Service (CAS) number. In some cases, both a primary and secondary category is listed, if the pollutant is known to exist as both types within air pollutant streams. For example, many combustion products, such as dioxins, furans, and polycyclic aromatic hydrocarbons (PAHs), are known to exist both in the vapor state, as well as being bound to particulate matter. Where both primary and secondary types are listed, the primary form is considered to dominate from the perspective of overall mass emissions. Therefore, this type should be used to assign control efficiency ranges from the control efficiency database. However, when applying a control efficiency estimate to a TAP species that exists in two different phases, one should consider a more conservative estimate than the representative control efficiency (e.g. lower end of range, one-half of the representative value).

Various criteria were used in the assignment of each TAP to the four categories as presented in Appendix B. Among these were previous experience working with emissions of a TAP species, vapor pressure [e.g., >1 millimeters of Hg column @ 20 degrees Celsius (°C)], and physical state at ambient conditions (or at elevated temperatures for combustion products).

The control efficiencies assigned to the four categories (i.e. VOT, POT, PIT, and GIT) are taken from applicable data for criteria pollutants. For example, control efficiencies for VOT and POT are generally assumed to be comparable to the applicable efficiency for TOG. Also, efficiencies for POT and PIT using PM control equipment are generally assumed to be equivalent to the applicable PM10 efficiency. Based on comments from MPCA, we assigned the PM2.5 control efficiency to POT and PIT in cases where the control could be used on combustion sources (e.g. fabric filters). We agree that the PM2.5 efficiency better corresponds to the size range of particulate TAP species from combustion sources. GIT control efficiencies were assigned based on the control efficiency for SO2.

In addition to the TAP physical state issue described above, another confounding issue related to the assignment of control efficiency is inter-species variability within a TAP category. For example, some organic TAPs are more resistant to thermal oxidation than others. Hence, for a given temperature and residence time, some TAPs will be combusted with a higher efficiency than others. As an illustration, sample groupings of several TAPs are shown in Table 2 (Pennington, 1996):

- *Group 1 compounds*: require an oxidation temperature of 1,800 degrees Fahrenheit (°F) or higher and a retention time of 0.5 to 1.0 second to achieve destruction efficiencies of 99 percent or greater.

- *Group 2 compounds*: these are halogenated compounds and require slightly longer retention times than Group 1 to achieve 99 percent destruction. In addition, additional scrubbing downstream may be necessary to control the resulting hydrogen chloride gas of hydrochloric acid emissions.

- *Group 3 compounds*: these are more difficult to destroy, requiring higher temperatures (1,800 to 2,000 °F) and longer retention times (1 to 2 seconds) to meet destruction efficiencies of 99 percent or greater. They may also require additional scrubbing downstream.

For thermal destruction controls, the user should consider assigning more conservative control efficiencies for organic TAP species in Groups 2 and 3, than for Group 1.

Table III-1. Sample Organic TAPs Grouped by Ease of Thermal Destruction

Group 1	Group 2	Group 3
Acetone Benzene Ethylene Methyl Ethyl Ketone Methyl Isobutyl Ketone Normal Butyl Alcohol Propylene Toluene	Chloroform Methylene Chloride Freon 113 1,1,1-Trichloroethane	Glycol Ethers Styrene Tetrachloroethylene

(adapted from Pennington, 1996)

IV. REFERENCES

Pechan, 2005. *Update of Control Equipment Data to Support MPCA's Control Equipment Rule: Technical Memorandum #1 – Research Outline,* prepared by E.H. Pechan & Associates, Inc., prepared for the Minnesota Pollution Control Agency, March 24, 2005.

Pennington, 1996. Pennington, R.L., "Options for Controlling Hazardous Air Pollutants", *Environmental Technology*, pp. 18-24, November/December 1996.

Roe et al, 1998. Roe, S.M., J. Reisman, R. Strait, E. Albright, and K. Kataoka, *Identification of Point Source Emission Controls and Determination of Their Efficiencies and Costs*, prepared for the California Air Resources Board, prepared by E.H. Pechan & Associates, Inc., April 30, 1998.

Sharp, 2005. A. Sharp, Sharp Environmental Systems, personal communication with Y. Hsu, E.H. Pechan & Associates, Inc., May 2005.

APPENDIX A. DEVICE DESCRIPTIONS

CONTENTS

Page

Adsorption: Various Adsorbents A-5
Biofiltration A-8
Catalytic Oxidizer (Catalytic Incinerator) A-11
Charged Scrubber A-14
Condensation Scrubber A-18
Contact Condenser (Barometric Condenser) A-20
Cryogenic Condensation A-21
Cyclone (single) A-22
Direct Flame Thermal Oxidizer (Thermal Incinerator) A-25
Dry Electrostatic Precipitator A-27
Fabric Filter (Pulse-jet, Reverse-air, Mechanical Shaker) A-31
Flameless Thermal Oxidation A-37
Flaring A-38
Fluidized Bed Dry Scrubber A-40
Fluidized Bed Catalytic Incineration A-41
Gravel Bed Filter A-42
Gravel Bed Moving Filter and Gravel Bed Moving Filter - Electrostatically Augmented A-44
Gravity Collector (Expansion Chamber, Settling Chamber, Elutriators) A-46
High Energy Corona A-48
Mat or Panel Filter – Conventional and High Efficiency A-49
Mechanically-Aided Scrubber A-51
Mechanically-Aided Separator A-53
Mist Eliminator - Blade-Type A-55
Mist Eliminator - Mesh-Type A-57
Momentum Separator A-59
Multiple Cyclone w/o Fly Ash Reinjection A-61
Non-Selective Catalytic Reduction, Rich Burn Engines A-63
Ozonation A-64
Packed-Bed Scrubber (Fiber-Bed, Moving-Bed, Cross-Flow, Grid-Packed) A-66
Packed Column - Gas Absorption A-70
Photocatalytic Oxidation A-73
Refrigerated Condenser A-74
Regenerative Catalytic Oxidizer A-75
Regenerative Thermal Oxidation A-76
Selective Catalytic Reduction A-77
Selective Non-Catalytic Reduction A-79
Silent Discharge Plasma Technology A-81
Spray Chamber Wet Scrubber (Spray Tower, Mist Scrubber, Cyclonic Spray Tower, Vane-type Cyclonic Tower) A-82
Supplement for Thermal Oxidation Controls: PM Control by Incinerators A-85
Thermal Reduction, Adipic Acid A-88
Tray-Type Gas Absorption Column A-89

Tray-Type Scrubber [Impingement Plate, Perforated Plate, Horizontal Impingement-Plate (Baffle)] A-91
Tube and Shell Condenser A-93
Vapor Recovery System Stage I – Bulk Plants and Terminals A-94
Venturi or Orifice Scrubber A-95
Water Blanket A-98
Water Curtain A-99
Wet Electrostatic Precipitator A-100
Wet Rotoclone A-103
Wet Scrubber (General, Not Classified) A-104
References A-105

Adsorption: Various Adsorbents

Adsorption is one of the most widely applied control technologies for organic vapors. In the adsorption process, organics are selectively collected on the surface of a porous solid. Activated carbon is by far the adsorbent most often used for low organic gas concentrations because of its low cost and relative insensitivity to water vapor at relative humidities below about 50 percent (EPA, 1995a). Other common adsorption media include silica and alumina-based adsorbates (molecular sieves), and synthetic resins (AWMA, 1992). In addition, recently developed hydrophobic zeolites have been incorporated into systems which, in principle, are similar to those based on carbon. Recovered solvent can often be reused directly in the process stream.

The applicable EPA control device codes for this category are 048 (Activated Carbon Adsorption) and 084 (Activated Clay Adsorption). Since activated carbon adsorption is the most common, 048 was selected as the MPCA code.

For VOC Control

Description

An activated carbon adsorption device is typically a two-bed system. VOC-laden air is passed through one bed at a time and treated. Over time, the carbon pore spaces begin to fill progressively through the bed. When the entire bed becomes saturated, the working capacity is exceeded; this is referred to as "breakthrough." Breakthrough is detected by either a measured decrease in efficiency or by an increase in pressure drop across the bed. To maintain constant high efficiency, the bed should be taken offline and the gas shifted to the other bed before the working capacity is approached.

After being taken offline, the saturated bed is regenerated, or desorbed, by backflushing the carbon with steam, by reducing the pressure in the bed to a sufficiently low pressure (vacuum desorption), or by replacing the carbon and disposing of or desorbing the saturated adsorbent offsite. If steam is used, the steam discharge is condensed and the vapors can be incinerated or recovered. About three to five percent of organics remain on virgin activated carbon and cannot be desorbed.

The cycle time of an adsorption bed may be several hours to several days. The carbon adsorbate can only be regenerated a finite number of times before it must be replaced. Typically, replacement is necessary every one to five years.

Some systems are nonregenerable, that is, they are shipped off-site for desorption or reactivation. These systems are applicable at sites where the inlet waste gases contain less than 100 ppmv of organic vapor and/or are difficult to desorb, such as when used for odor control or control of indoor air (RTI, 1995).

Application

Adsorption is best suited for control of VOCs and HAPs with intermediate molecular weights between 40 and 150 and with boiling points between 100°F and 500°F. Carbon adsorption is well suited to variations in process air streams and VOC concentration. Smaller compounds do not adsorb well, and larger compounds cannot be removed (desorbed) during regeneration.

Carbon adsorption is particularly well suited to the recovery of aromatic and saturated (straight) hydrocarbons and acetates. A partial list of other recoverable solvents includes toluene, heptane, hexane, cellosolve, carbon tetrachloride, acetone, ethyl alcohol, ethyl acetate, methylethyl ketone (MEK), naphthalene, and methylene chloride (Ruhl, 1994).

The maximum practical inlet concentration is approximately 10,000 ppmv. Permissible inlet concentrations are typically limited by the adsorption capacity of the carbon bed or safety problems posed by high bed temperatures produced by the heat of adsorption and presence of flammable vapors. Outlet concentrations of about 50 ppmv can be routinely achieved and concentrations as low as 10 to 20 ppmv can be achieved with some compounds (EPA, 1991a).

Gas entering the adsorber should be "dry." If the entering gas is "wet" with either water or organic droplets, they will tend to clog the surface of the carbon particle and reduce its effective life. Carbon adsorption systems are often preceded by refrigeration systems which condense much of the water and heavy organics to prevent clogging.

Carbon adsorption using conventional and chemically impregnated carbons is also widely used for controlling inorganic vapors such as Hg, nickel carbonyl, phosgene, and amines. When Hg vapors are passed through a bed of sulfur-impregnated carbon, the Hg vapors react with sulfur to form a stable mercuric sulfide. Over 95 percent of the Hg removed in this way can be recovered for reuse (EPA, 1991a).

Adsorption is used to control organic vapors in a wide variety of industries.

Control Efficiency

The typical control efficiency range is from 90 to 99 percent (EPA, 1991a; EPA, 1995a). Ketones (acetone, MEK) are chemically very active and may pose difficulties to a carbon adsorption system and result in lower efficiency than otherwise expected. At concentrations greater than 1000 ppmv, efficiencies can exceed 95 percent. At gaseous pollutant concentrations from 200 to 1000 ppmv, carbon adsorption can achieve >90 percent control efficiency (AWMA, 1992).

Most reported removal efficiencies for inorganic vapors are for activated carbon and impregnated activated carbon, and they range from 90 to >99 percent (EPA, 1991a).

For SOx Control

Description

Sulfur dioxide in a waste gas stream is adsorbed onto activated carbon (coke from peat, lignite, or hard coal) and zeolite (Chabazite), generally in a cross-flow adsorber. The adsorbed SO_2 reacts with oxygen and water to form sulfuric acid, filling the pores in the carbon. Before regeneration, the carbon bed can be screened to remove fly ash. The spent carbon is regenerated in a desorber by hot gas or hot sand, creating a stream of concentrated (20 to 30 percent by volume) SO_2 which can be passed to a Claus plant to make elemental sulfur, an acid plant to make sulfuric acid, or condensed to form liquid SO_2. Some of the carbon is consumed as a reductant used to convert SO_3 to SO_2 (IEA, 1989; Satriana, 1981).

Application

Carbon adsorption systems for SO_2 control have been used at demonstration and pilot-scale coal- and oil-fired power plants (IEA, 1989).

Control Efficiency

The typical control efficiency range is from 70 to 80 percent (IEA, 1989; Satriana, 1981).

Monitoring Parameters

Flue gas humidity, temperature, pressure drop, **inlet and outlet pollutant concentrations**.

Record-Keeping Requirements

Daily readings of flue gas humidity, temperature, pressure drop; continuous or vendor-specified monitoring of inlet and outlet VOC concentrations; recording of carbon replacement or regeneration frequency.

Biofiltration

Description

In biofiltration, vapor-phase organic contaminants are passed through a bed of biologically active material, (primarily mixtures based on soil, compost, or peat) and adsorb to the material surface, where they are degraded by microorganisms in the material. Specific strains of bacteria may be introduced into the filter and optimal conditions provided to preferentially degrade specific compounds. Some newer systems have replaced soil with a specially prepared biomass support media that improves performance and has a lower pressure drop than soil (Harrison, 1996).

Although many different types of biofilters have been designed, the gas to be treated is often distributed over the bottom of the bed and forced upward through the media. The mechanism of the biofiltration process includes a combination of adsorption, absorption, and microbial degradation.

The filter does not require regeneration, as the contaminants are destroyed and not just adsorbed in the process.

There is no applicable EPA control device code for this device. Pechan assigned a new code 506 to this device.

Application

The effectiveness of biofiltration is dependent on the biodegradability of the contaminants. Under proper conditions, biofilters can remove an extremely high percentage of selected contaminants into carbon dioxide, water, and salts. Biofiltration is used primarily to treat odors, nonhalogenated VOCs, and fuel hydrocarbons. Halogenated VOCs may be treated, however the process is less effective and may not be economically feasible (Leson and Winer, 1991). Biofiltration is best suited for dilute gas streams; less than 1000 ppm of VOCs, typical commercial applications are in the 5 to 500 ppm range (Standefer, 1996). Maximum concentration is around 10,000 milligrams per cubic meter or 2,500 ppm for a compound with molecular weight of 100 (Harrison, 1996).

Biofiltration is subject to several limitations. The rate of influent flow is directly related to the size of the biofilter, which may result in relatively large space requirements. A large volume of filter media is usually required to provide adequate residence time for adsorption/destruction (up to 60 seconds) (Wani et al., 1997). Biofiltration is only effective for contaminants with high adsorption and degradation rates. Fugitive fungi may be a problem. Low temperatures may slow or stop removal unless the biofilter is climate controlled. A period of weeks or months may be necessary for the microbes to acclimate and condition themselves. Sources with highly variable concentrations are not well-suited to biofiltration.

Commercial VOC applications include the chemical and petrochemical industry, oil and gas industry, synthetic resins, paint and ink, pharmaceutical industry, contaminated soil remediation, and waste and wastewater treatment. Odor abatement applications have included sewage treatment, slaughter houses, rendering, gelatin and glue plants, agricultural and food processing industry, meat and fish, packing, tobacco, cocoa and sugar industry, bulk handling terminals, and flavor and fragrance production (Harrison, 1996; Wani et al., 1997).

Control Efficiency

The typical control efficiency range is from 75 to 99 percent. When design criteria are met, removal rates for BTEX (benzene, toluene, ethylbenzene, and xylenes) and halogenated hydrocarbons are in the range of 90 to 99 percent. For volatile PAHs, between 75 and 90 percent are removed (AirScience, 1996; Vembu and Walker, 1995). Other control efficiency data from commercial installations are (Wani, 1997, CARB, 1999):

Facility Type	Control Efficiency	Compounds
Composting	up to 99%	odors
	52 - 99%	VOCs
	over 80%	reduced sulfur compounds
	75 – over 90%	NOx
Landfill Operations	89 - 96%	NH_3
	84 - 86%	NMHC
Wood Products	93%	VOC
Hardboard Plant	over 95%	Odors
Pharmaceutical	over 99%	VOCs

Biofiltration of NOx by denitrification from contaminated air streams has been explored (CARB, 1999). Apel et al. (1995) used denitrifying bacteria grown on wood compost to remove NOx under anoxic conditions. They achieved removals of over 90 percent in the biofilter unit. Denitrification activity was also observed in a synthetic media biofilter treating toluene (du Plessis et al., 1996). The presence of a thick biofilm, which filled the media pores, allowed for formation of anaerobic zones where denitrification likely took place. NOx concentrations were reduced from 60 ppmv to 15 ppmv (75 percent reduction).

Monitoring Parameters

Bed temperature, moisture, nutrients (nitrogen, phosphorus, potassium), pH, and inlet VOC concentration.

Most microbes can survive and flourish in a temperature range of 60 to 105°F (30 to 41°C) (EPA, 2003). It is important to monitor bed temperature at least daily, but every eight hours would be safer. A high temperature alarm on the emissions inlet is also a good safety precaution. Microbes need moisture to survive and moisture creates the bio-film that removes (absorbs) pollutants from an air stream so that they can be assimilated by microbes. Microbes need a diet of balanced nutrients to survive and propagate. Pollutants provide the main source of food and energy, but microbes also require macronutrients to sustain life. Most biofilters perform best when the bed pH is near 7, or neutral. Some pollutants form acids when they decompose. Examples of these compounds are: hydrogen sulfide, organic sulfur compounds, and halogens (chlorine, fluoride, bromine and iodine). Production of acids over time will lower pH and will eventually destroy microbes. If a process emits pollutants that produce acids, a plan must be developed to neutralize these acids. Biofiltration is best suited for dilute gas streams – less than 1000 ppm of VOCs (EPA, 2003).

Record-Keeping Requirements

Records of daily monitoring of bed temperature, moisture, nutrient supply (nitrogen, phosphorus, potassium), pH, and inlet VOC concentration.

Catalytic Oxidizer (Catalytic Incinerator)

Description

The catalytic oxidizer is designed primarily for the destruction of dilute VOC emission streams. The system is referred to as an afterburner if it is used to control gases from a process where combustion was not complete. Catalytic incinerators operate very similar to thermal/recuperative incinerators, with the primary difference that the gas, after passing through the flame area, passes through a catalyst bed. The catalyst has the effect of increasing the oxidation reaction rate, enabling destruction at lower reaction temperatures than in thermal incinerator units. Catalysts, therefore, also allow for smaller incinerator size. Catalysts typically used for VOC incineration include platinum and palladium. Other formulations include metal oxides, which are used for gas streams containing chlorinated compounds (EPA, 1998).

In a catalytic incinerator, the gas stream is introduced into a mixing chamber, where it is also heated. The waste gas usually passes through a recuperative heat exchanger where it is preheated by post combustion gas. The heated gas then passes through the catalyst bed. Oxygen and VOC migrate to the catalyst surface by gas diffusion and are adsorbed onto the catalyst active sites on the surface of the catalyst where oxidation then occurs. The oxidation reaction products are then desorbed from the active sites by the gas and transferred by diffusion back into the gas stream (EPA, 1998).

Particulate matter can rapidly coat the catalyst so that the catalyst active sites are prevented from aiding in the oxidation of pollutants in the gas stream. This effect of PM on the catalyst is called blinding, and will deactivate the catalyst over time. Because essentially all the active surface of the catalyst is contained in relatively small pores, the PM need not be large to blind the catalyst. No general guidelines exist as to the PM concentration and size that can be tolerated by catalysts, because the pore size and volume of catalysts vary widely.

For economic reasons, the great majority of catalytic oxidizers are equipped with a heat exchanger to recover waste heat from the exhaust gas. Thus equipped, the system may also be referred to as a "recuperative" system. The recovered heat is used to preheat the waste gas entering the system. The benefit of a heat exchanger is that it reduces the auxiliary fuel requirement of the system, resulting in lower operating costs. The presence or lack of a heat exchanger will affect the annualized costs, but not the control efficiency of the system.

In a catalytic incinerator, waste gas is typically delivered at 10 to 30 feet per second and heated between 600 to 800°F before entering the catalytic reactor. The oxidation reaction takes place in the catalyst bed, and the combustion products (water vapor, carbon dioxide, inerts, and unreacted vapors) are discharged at a higher temperature, typically 800 to 1300°F (Budin and Kratz, 1995).

Destruction efficiency depends on temperature, residence time, adequate oxygen, and complete mixing. Oxidation occurs when VOCs are heated to their autoignition temperature in the presence of sufficient oxygen. Autoignition temperatures differ from chemical to chemical. The higher this temperature, the more expensive it is to destroy the compound. The longer the residence time at the autoignition temperature, the more complete the destruction. Adequate mixing with combustion air is also necessary to ensure complete oxidation.

The applicable EPA control device codes for this category are 019 (Catalytic Afterburner), 020 (Catalytic Afterburner with Heat Exchanger), 109 (Catalytic Oxidizer), and 116 (Catalytic Incinerator). Pechan selected 109 as the MPCA code.

Application

Catalytic oxidation is most suited to systems with lower exhaust volumes, when there is little variation in the type and concentration of VOCs, and where catalyst poisons or other fouling contaminants such as silicone, sulfur, heavy hydrocarbons and particulates are not present (Renko, 1994). These systems are popular in controlling air streams in wastewater, groundwater, and soil remediation projects. Emission streams with high VOC concentrations should not be treated by catalytic incineration without dilution since such streams may cause the catalyst bed to overheat and lose its activity.

Catalysts have been developed that are relatively tolerant of compounds containing sulfur or chlorine. Chrome/alumina, cobalt oxide, and copper oxide/manganese oxide catalysts have been demonstrated to control emission streams containing chlorinated compounds. Catalysts may be in the form of a metal-mesh mat, a ceramic honeycomb, or packed spheres or pellets.

If sulfur and/or chlorine are present in the emission stream, the resulting gas will contain SO_2 and/or HCl. Depending on the concentration of these compounds in the flue gas and applicable regulations, scrubbing may be required to reduce the concentrations of these compounds.

The main advantage of catalytic incinerators is that they operate at much lower temperatures than thermal oxidizers, due to the use of catalysts that cause VOCs to react with oxygen at lower temperatures than in thermal units. Reduced operating temperatures mean greatly reduced fuel consumption and less stress on the materials of the system. Other advantages include relatively low NOx, CO, and carbon dioxide emissions, little or no insulation requirements, reduced fire hazards, and reduced flashback problems. Older catalyst systems had difficulty destroying chlorinated hydrocarbons; however, newer platinum and/or palladium catalyst formulations and other new catalyst developments have been effective in dealing with these streams (Herbert, 1993; Gay, 1997).

Disadvantages include: 1) high initial cost, 2) potential for irreversible damage such as catalyst poisoning (by phosphorous, bismuth, lead, arsenic, antimony, Hg, iron oxides, tin, zinc, fluorine, silicon dust) and excessive temperatures, which can sinter the catalyst, 3) potential for less serious reversible damage caused by sulfur, zinc, and solid organic materials, 4) particulate often must be removed before entering the catalyst bed or fouling can occur, and 5) need to dispose of spent catalyst.

Control Efficiency

The typical control efficiency range for VOCs is from 90 to 99 percent. Generally, for low pollutant concentrations (<100 ppmv), control efficiencies range from 90 to 95 percent. For higher pollutant concentrations (>100 ppmv), control efficiencies of between 95 and 99 percent can be achieved (AWMA, 1992; EPA, 1991a).

The relative destructibility of alcohols is high. Other compounds (listed in order of decreasing destructibility) are cellosolves/dioxane, aldehydes, aromatics, ketones, acetates, alkanes, and chlorinated hydrocarbons. However, between 98 to 99 percent destruction efficiency for all compounds can still be achieved with sufficiently low space velocities and/or high inlet temperature.

The average VOC control efficiency at gravure printing presses ranges from 94 to 99.5 percent when a total enclosure capture system with an add-on destruction device (either catalytic, regenerative or thermal incineration, or carbon adsorption) is used (TRC, 1993). Flexographic printing presses controlled by catalytic incineration may achieve from 90 to 98 percent overall efficiency (AWMA, 1992). A metal oxide catalyst must be used on flexographic printing presses to avoid poisoning by chlorinated solvents.

Monitoring Parameters

Combustion zone temperature, PM and **oxygen** concentrations, flue gas flow rate, auxiliary fuel supply rate, and other specifications required by the equipment vendor.

Excessive temperatures can sinter the catalyst. Sufficient oxygen and residence time are required to provide optimal efficiency. PM often coats (or "blinds") the catalyst so that the catalyst's active sites are prevented from aiding in the oxidation of pollutants in the gas stream. Examples are gases containing chlorine, sulfur, and other atoms, such as phosphorous, bismuth, lead, arsenic, antimony, mercury, iron oxide, tin, and zinc that may deactivate the supported noble metal catalysts (EPA, 2003).

Record-Keeping Requirements

Recording of continuous temperature readouts, PM and oxygen concentrations, flue gas flow rate, and auxiliary fuel supply rate; other specifications recommended by the equipment vendor; source-specific requirements by permit (e.g. inlet/outlet pollutant concentrations).

Charged Scrubber

Description

Charged scrubbers use electrostatic effects to improve collection efficiencies for fine PM with wet scrubbing. Pre-charging the PM in the gas stream can significantly increase scrubber collection efficiency for submicron particles, without increasing the pressure drop of the scrubber and thus operating costs. However, electric power costs associated with charging the scrubber increase scrubber operating costs. When both the particles and droplets are charged, collection efficiencies for submicron particles are highest, approaching that of an ESP. The PM can be charged negatively or positively, with the droplets given the opposite charge (McIlvaine, 1995).

This is a new device. EPA doesn't have an applicable code for this device. Pechan assigned a new code 503 to it.

Application

Charged scrubbers have been applied to control PM emissions from coke manufacturing and the lead and aluminum production industries. Typically, they are applied where it is necessary to obtain high collection efficiencies for fine PM. Thus, they are applicable to controlling emission sources with high concentrations of submicron particles.

Control Efficiency

Information on control efficiency ranges for charged scrubbers was not identified. Based on professional judgment, the control efficiency range for charged scrubbers was assumed to be the same as that specified for venturi scrubbers.

Monitoring Parameters:

Monitoring parameters can include one or more of the: **Liquid flow rate**, pressure drop, blowdown rate, electrical values (kV, mAmp), and gas flow rate.

Record-Keeping Requirements:

Daily records of blowdown rate, electrical voltage or current, and gas flow rate to demonstrate adherence to vendor specifications.

Control Efficiency

Wet scrubbers are generally not used for fine PM applications because high liquid to gas ratios (greater than 3 liters per cubic meter (l/m3) are required). Collection efficiencies range from 70 to greater than 99 percent, depending upon the application. Cyclonic spray towers generally achieve collection efficiencies at the higher end of the range (EPA, 2003).

AP-42 (EPA, 1995b) chapters were reviewed to identify particle size distribution profiles for scrubbers that could be used to calculate control efficiencies for PM and the cumulative mass for particles ≤10 µm and ≤2.5 µm. A total of 11 particle size distributions were identified for different industries. For 8 of the particle size distributions, AP-42 (EPA, 1995b) did not specify the type of scrubber. Three of the particle size distributions are for venturi scrubbers. The PM, PM10, and PM2.5 control efficiencies calculated from the venturi scrubber profiles were within the range of control efficiencies calculated from the 8 profiles for which the type of scrubber was not specified. Thus, all 11 particle size distribution profiles were used in developing the control efficiency ranges for this control equipment code.

For PM, the lowest control efficiency calculated from the 11 profiles was 89.74 percent. For PM10, the lowest control efficiency calculated from the 11 profiles was 68 percent. However, in EPA (1973a), a PM control efficiency of 70 percent was identified for spray chamber scrubbers and 55 percent for tray-type scrubbers. Therefore, 55 percent was selected as the low-end control efficiency for scrubbers in general.

For PM2.5, the lowest control efficiencies calculated from the profiles were 25, 30, and 50 percent. Given the variability in possible scrubber designs for the wide variety of applications to which scrubbers may be applied, 25 percent was selected as the low-end of the range for PM2.5.

The high-end of the range for PM and PM10 is based on the assumption that scrubber design, operation, and maintenance technology has advanced over the past 20 years such that some types of scrubbers (e.g., venturi, condensation, and charged) could be designed to achieve >99.9 percent control of PM and PM10. For PM2.5, the high-end of the control efficiency range is based on the high-end control efficiency calculated from AP-42 particle size distribution profiles, which is 96.67 percent. This value was rounded to 97 percent. Given that the form of the PM National Ambient Air Quality Standards (NAAQS) is now PM2.5 instead of PM10, it is assumed that vendors will be optimizing scrubber systems to achieve high PM2.5 control efficiencies.

For Inorganic Gases Control (SOx, Chromic Acid, Hydrogen Sulfide, Ammonia, Chlorides, Fluorides)

Description

Wet scrubbers are a general category of control device in which, for inorganic gases (e.g., SO_2) control, a liquid solution or liquid/solid slurry is used to absorb, and, in most cases, react with the inorganic gases in a waste gas stream. A vessel, into which both the solution or slurry and the waste gas are introduced, is used to maximize the contact between the inorganic gases in the waste gas and the reacting compounds in the solution or slurry. The design of the vessel and the manner in which the waste gas and the solution or slurry are introduced to the vessel are the means by which the reagent contact is controlled. Types of wet scrubber designs include: tray-type column, packed-bed column, mobile-bed column, venturi, and spray tower. Reagents used in wet scrubber systems include: calcium oxide (from lime), calcium carbonate (from limestone), magnesium oxide, sodium carbonate (soda ash), sodium hydroxide (caustic), sodium citrate, and ammonium hydroxide. Some wet scrubbing systems use a reagent which can be treated and reused and/or produces a saleable product, while other wet systems require that the spent reagent be treated and disposed of appropriately (EPA, 1981). Water is the most common solvent used to remove inorganic contaminants.

Application

Wet scrubbing systems have been the most popular type of FGD system used to control SO_2 in waste gas flows from coal- and oil-fired boilers at utilities and industrial facilities, metal smelters, pulp mills, and other sources of SO_2 (EPA, 1981).

Control Efficiency

For inorganic gases, control device vendors estimate that removal efficiencies range from 95 to 99 percent. The typical SO_2 control efficiency range is from 80 to >99 percent (EPA, 2003, EPA, 1981; Sondreal, 1993). The control efficiency is dependent upon the type of wet scrubber system used, the absorbing and/or reacting solution or slurry used, and the concentration of SO_2 in the treated waste gas flow. Most current applications have a removal efficiency greater than 90 percent (EPA, 2003). Thus, Pechan chose 90% as a representative control efficiency in the database.

For VOC Control

Description

Wet scrubbers can be used to remove organic compounds by absorbing the pollutants into the liquid solvent (e.g., hydrocarbon oils). The contact between the absorbing liquid and the vent gas is accomplished in counter current spray towers, scrubbers, or packed or plate columns (EPA, 2003). Hydrophilic VOC species may be absorbed by aqueous fluids. Amphiphilic block copolymers can be added to the water to absorb hydrophobic VOCs.

Application

VOC absorption, using wet scrubbers, is applied in chemical processing as a raw material and/or product recovery technique in the separation and purification of gaseous streams containing high concentrations of organics (e.g., in natural gas purification and coke by-product recovery operations).

Control Efficiency

For organic gases, removal efficiencies for gas absorbers vary for each pollutant-solvent system and with the type of absorber used. Most absorbers have removal efficiencies in excess of 90 percent, and spray tower absorbers may achieve efficiencies greater than 99 percent for some pollutant-solvent systems. EPA (2003) mentions a "typical collection" efficiency range from 50 to 95 percent. However, Pechan believes that EPA was referring to the control efficiency of the equipment, not the collection efficiency of a capture system. Lower control efficiencies represent flows containing relatively insoluble compounds at low concentrations, while the higher efficiencies are for flows which contain readily soluble compounds at high concentrations (EPA, 2003). Based on the available information, Pechan chose a representative efficiency for VOC of 90%.

Monitoring Parameters

Depending on the application, can be one or more of the following: **Liquid flow rate, flue gas pressure drop** and temperature, concentration of reacting solution or slurry if used, pH of absorbing solution.

Record-Keeping Requirements

Depending on the application, one or more of the following: Daily records of liquid flow rate, flue gas pressure drop and temperature, reacting solution or slurry if used, pH, reagent usage.

Condensation Scrubber

Description:

Condensation scrubbing is a relatively recent development in wet scrubber technology. Most conventional scrubbers rely on the mechanisms of impaction and diffusion to achieve contact between the PM and liquid droplets. In a condensation scrubber, the PM acts as a source of condensation nuclei for the formation of droplets. Generally, condensation scrubbing depends on first establishing saturation conditions in the gas stream. Once saturation is achieved, steam is injected into the gas stream. The steam creates a condition of supersaturation and leads to condensation of water on the fine PM in the gas stream. The large condensed droplets are then removed by one of several conventional devices, such as a high efficiency mist eliminator (EPA, 2003).

For PM applications, wet scrubbers generate waste in the form of a slurry. This creates the need for both wastewater treatment and solid waste disposal. Initially, the slurry is treated to separate the solid waste from the water. The treated water can then be reused or discharged. Once the water is removed, the remaining waste will be in the form of a solid or sludge. If the solid waste is inert and nontoxic, it can generally be landfilled. Hazardous wastes will have more stringent procedures for disposal. In some cases, the solid waste may have value and can be sold or recycled (EPA, 2003).

This is a new device. EPA doesn't have an applicable code for this device. Pechan assigned a new code 517 to this device.

Application:

Condensation scrubbers are typically intended to control fine PM with an aerodynamic diameter of between approximately 0.25 and 1.0 µm (Sun et al., 1994).

Condensation scrubbers are intended for use in controlling fine PM-containing waste-gas streams, and are designed specifically to capture fine PM which has escaped a primary PM control device. The technology is suitable for both new and retrofit installations. Condensation scrubbing systems are a relatively new technology and are not yet generally commercially available (Sun et al., 1994; EPA, 1998; EPA, 2003).

The fine fraction of PM emissions from a combustion source often contains cadmium and other metals. Use of a condensation scrubber to capture fine PM may provide an effective method of reducing the emission of metals (EPA, 2003).

For PM control from combustion sources, the flue gas enters a coagulation area (e.g., ductwork, a chamber, or a cyclone) to reduce the number of ultrafine particles, and then a gas conditioner to cool the gas to a suitable temperature and saturation state. This is generally accomplished by means of a waste heat recovery heat exchanger to reduce the temperature of the flue gas or by spraying water directly into the hot flue gas stream. It is usually not practical or cost effective to cool flue gases to temperatures below ambient values. Condensation scrubbers are generally intended to be used downstream of another scrubber (e.g. a venturi scrubber) which has already removed PM >1.0 µm aerodynamic diameter (EPA, 2003).

Control Efficiency

Collection efficiencies of greater than 99 percent have been reported for particulate emissions, based on study results (EPA, 2003).

Monitoring Parameters:

Pressure drop, relative humidity, steam supply rate, blowdown rate, electrical values (kV, mAmp), gas flow rate

Record Keeping Requirements:

Daily recording of blowdown rate, electrical voltage or current, gas flow rate to show adherence to vendor specifications.

Contact Condenser (Barometric Condenser)

Description

Contact condensers recover VOCs by providing direct contact and intimate mixing between the cooling medium and vapors/condensate. Typical contact condenser types are barometric and jet.

The most common type of direct contact condenser is the countercurrent barometric condenser, which provides a rain of cooling water through which the vapor rises, condenses, and is carried away by the water. The condenser contains drip plates arranged in a staggered step fashion to enhance mixing. The condenser is elevated so that water can discharge by gravity from the vacuum in the condenser.

The jet, or wet, condenser uses high velocity jets of water in co-current flow with vapor. The high pressure jets promote condensation and force non-condensable gases out the tailpipe (Perry and Green, 1984).

The applicable EPA control device codes for this category are 074 (Barometric Condenser) and 132 (Condenser).

Application

Surface condensers constitute the majority of condensers used for air pollution control. However, contact condensers are simpler, less expensive to install and operate, and require less auxiliary equipment and maintenance than indirect, or surface condensers. A disadvantage of contact condensers is that the condensate cannot be reused and further treatment or separation may be necessary (Theodore and Buonicore, 1988).

Control Efficiency

The typical control efficiency range for this control is 50 to 96 percent. Efficiencies for contact condensers are assumed to be the same as for surface condensers (e.g. tube and shell type). For tube and shell condensers, the assumed representative efficiency for VOC and VOT is 90 percent.

Monitoring Parameters:

Water flow rate and temperature, flue gas temperature.

Record-Keeping Requirements:

Daily records of water flow rate and temperature, flue gas temperature.

Cryogenic Condensation

Description

Cryogenic condensation uses the cooling value of liquid nitrogen in a condenser to recover VOCs emitted during manufacturing processes. The system condenses VOC emissions by vaporizing liquid nitrogen to provide the cooling source to indirectly cool the process stream to low temperatures.

Successful condenser designs need precise temperature controls to minimize freezing and mist formation, and contain a defrosting system to remove frozen material from the heat exchanger surface (Zeiss and Ibbetson, 1997). Cryogenic condensation systems often have a pre-cooler, which may be cooled by a separate refrigeration system, the cold nitrogen exiting the condenser, or the exhaust air leaving the main condenser. Using a pre-cooler allows most of the water vapor to be collected separately (EPA, 2001).

There is no applicable EPA control device code for this device. Thus, Pechan assigned a new code 508 to this device.

Application

Cryogenic cooling is most applicable to emission streams smaller than 10,000 cfm, although it has been applied to larger flows (EPA, 2001). Cryogenic condensation is best suited to industries that already use significant quantities of liquid nitrogen in their normal processes for inerting, blanketing, and purging, such as pharmaceutical and specialty chemicals. The nitrogen can be reused onsite, making additional nitrogen purchases unnecessary.

Control Efficiency

The typical control efficiency range for VOCs is from 95 to >99 percent (Davis and Zeiss, 1997). The control efficiency varies according to the condensation temperature, which can be automatically controlled by adjusting the amount of nitrogen flow delivered to the process condensers.

Monitoring Parameters:

Nitrogen flow rate, reactor temperature.

Record-Keeping Requirements:

Daily readings of nitrogen flow rate, reactor temperature.

Cyclone (single)

Description

Cyclones use inertia to remove particles from the gas stream. The cyclone imparts centrifugal force on the gas stream, usually within a conical shaped chamber. Cyclones operate by creating a double vortex inside the cyclone body. The incoming gas is forced into circular motion down the cyclone near the inner surface of the cyclone tube. At the bottom of the cyclone, the gas turns and spirals up through the center of the tube and out of the top of the cyclone (AWMA, 1992).

Particles in the gas stream are forced toward the cyclone walls by the centrifugal force of the spinning gas but are opposed by the fluid drag force of the gas traveling through and out of the cyclone. For large particles, inertial momentum overcomes the fluid drag force so that the particles reach the cyclone walls and are collected. For small particles, the fluid drag force overwhelms the inertial momentum and causes these particles to leave the cyclone with the exiting gas. Gravity also causes the larger particles that reach the cyclone walls to travel down into a bottom hopper. While they rely on the same separation mechanism as momentum separators, cyclones are more effective because they have a more complex gas flow pattern (AWMA, 1992).

Cyclones are generally classified into four types based on how the gas stream is introduced into the device and how the collected dust is discharged. The four types include tangential inlet, axial discharge; axial inlet, axial discharge; tangential inlet, peripheral discharge; and axial inlet, peripheral discharge. The first two types are the most common (AWMA, 1992).

Another high-efficiency unit, the wet cyclonic separator, uses a combination of centrifugal force and water spray to enhance control efficiency.

The applicable EPA control device codes for this group of devices are 007, 008, and 009, which correspond to High, Medium (conventional), and Low (high throughput) efficiency cyclones. Another applicable code is 075 (Single Cyclone).

Application

Cyclones are primarily used to control PM10. However, there are high efficiency cyclones designed to be effective for PM less than or equal to 10 μm and less than or equal to 2.5 μm in aerodynamic diameter (PM10 and PM2.5). Although cyclones may be used to collect particles larger than 200 μm, gravity settling chambers or simple momentum separators are usually satisfactory for controlling these large particles and are less subject to abrasion. (EPA, 2003)

Cyclones are designed for many applications and are typically categorized as high efficiency, conventional, or high throughput. High efficiency cyclones are likely to have the highest pressure drops of the three types. High throughput cyclones are designed to treat large volumes of gas with a low pressure drop. Each of the three types has the same basic design, but the cyclone dimensions are varied to achieve different collection efficiencies, pressure drops, and operating requirements (AWMA, 1992; EPA, 1982).

Control Efficiency

Many factors affect the collection efficiency of cyclones. Cyclone efficiency generally increases with (1) particle size and/or density, (2) inlet duct velocity, (3) cyclone body length, (4) number of gas revolutions in the cyclone, (5) ratio of cyclone body diameter to gas exit diameter, (6) dust loading, and (7) smoothness of the cyclone inner wall. Cyclone efficiency will decrease with increases in (1) gas viscosity, (2) body diameter, (3) gas exit diameter, (4) gas inlet duct area, and (5) gas density. A common factor contributing to decreased control efficiencies in cyclones is leakage of air into the dust outlet (EPA, 1973a).

Control efficiency ranges for single cyclones were developed for the three different classifications (i.e., conventional, high-efficiency, and high-throughput, see Table A-1). Although the literature uses these classifications when discussing the different designs of cyclones, published reports containing control efficiency test data for existing units generally do not identify the cyclone classification. Thus, it is difficult to classify published control efficiency data by the type of cyclone. The control efficiency ranges developed are based on professional judgment and some guidance obtained from the technical literature.

Table A-1. Cyclone Classifications

Ratio Dimensions	High Efficiency	Conventional	High-Throughput
Height of inlet, H/D	0.44	>0.44 and <0.80	0.80
Width of inlet, W/D	0.2	>0.2 and <0.375	0.375
Diameter of gas exit, De/D	0.4	>0.4 and <0.75	0.75
Length of vortex finder, S/D	0.5	>0.5 and <0.875	0.875

D: cyclone diameter

High efficiency single cyclones are designed to achieve higher control of smaller particles than conventional cyclones. According to Cooper and Alley (1994), high efficiency single cyclones can remove 5 μm particles at up to 90 percent efficiency, with higher efficiencies achievable for larger particles. The control efficiency range for high efficiency single cyclones is estimated to be 80 to 99 percent for PM, 60 to 95 percent for PM10, and 20 to 70 percent for PM2.5.

The control efficiency range for conventional single cyclones is estimated to be 70 to 90 percent for PM, 30 to 90 percent for PM10, and 0 to 40 percent for PM2.5. The control efficiency ranges for conventional cyclones were selected to represent existing units that have been minimally maintained and/or were installed to meet emission limits established many years ago that would be considered relatively lenient compared to current emission limits.

According to Vatavuk (1990), high throughput cyclones are only guaranteed to remove particles greater than 20 μm, although collection of smaller particles does occur to some extent. The control efficiency range for high-throughput cyclones is estimated to be 80 to 99 percent for PM, 10 to 40 percent for PM10, and 0 to 10 percent for PM2.5.

Monitoring Parameters

Pressure drop. Pressure drop is an important parameter because it relates directly to operating costs and control efficiency. Higher control efficiencies for a given cyclone can be obtained by higher inlet velocities, but this also increases the pressure drop.

Record Keeping Requirements

Daily recording of pressure drop.

Direct Flame Thermal Oxidizer (Thermal Incinerator)

Description

The direct flame thermal oxidizer is a simple combustion device designed primarily for the destruction of VOCs. The system is referred to as an afterburner if it is used to control gases from a process where combustion was not complete.

The typical direct flame thermal oxidizer consists of burners, which ignite the fuel and organic, and a chamber, which provides the residence time for the oxidation process.

The four conditions necessary for maximum destruction are temperature, time, turbulence (for mixing), and the availability of oxygen. VOCs heated to the autoignition temperature in the presence of sufficient oxygen will oxidize to form carbon dioxide and water. Autoignition temperatures differ from chemical to chemical. The higher this temperature, the more expensive it is to destroy the compound. Adequate residence time is necessary for complete combustion; other variables being equal, longer residence times result in higher destruction efficiencies. Adequate mixing with sufficient combustion air is imperative to ensure complete oxidation. These variables are inter-dependent, and all affect the rate and efficiency of the combustion process.

Direct flame oxidizers require auxiliary fuel to achieve the elevated temperatures needed for high chemical reaction rates. Thermal destruction of most organic compounds occurs between 590°C and 650°C (1100°F and 1200°F); however, most thermal oxidizers operate in the 1250 to 1600°F range for maximum destruction. Residence time is typically >0.5 seconds, but it may be less with systems with extremely good mixing. Average gas velocity ranges from 10 to 50 feet per second, with flows generally less than 50,000 scfm (AWMA, 1992).

For economic reasons, the great majority of thermal oxidizers are equipped with a heat exchanger to recover waste heat from the exhaust gas. Thus equipped, the system may also be referred to as a "recuperative" system. The recovered heat is used to preheat the waste gas entering the system. The benefit of a heat exchanger is that it reduces the auxiliary fuel requirement of the system, resulting in lower operating costs. The presence or lack of a heat exchanger will affect the annualized costs but not the control efficiency of the system.

The applicable EPA control device codes for this category are 021 (Direct Flame Afterburner), 022 (Direct Flame Afterburner with Heat Exchanger), 131 (Thermal Oxidizer), and 133 (Incinerator)

Application

Thermal oxidizers are used to control VOCs from many industrial and commercial processes that use solvents directly or as a carrier media, such as electronics manufacturing, the aerospace industry, printing, painting, laminating, etc.

Design conditions depend on the type, concentration and quantity of organic vapor to be destroyed. Thermal oxidizers can be used only for relatively low organic vapor concentrations. The minimum inlet concentration is typically 20 ppmv. For safety, the concentration of the organics in the air entering the oxidizer is usually limited to less than 25 percent of the lower explosive limit (LEL). However, concentrations up to 50 percent of the LEL may be acceptable (Public Works, 1997).

Thermal oxidizers can accommodate minor fluctuations in flow, but are not well suited to streams with highly variable flow because the reduced residence time and poor mixing during increased flow conditions decreases the completeness of combustion. Incomplete combustion causes the combustion chamber temperature to fall, decreasing the equipment's destruction efficiency.

Depending on concentrations, thermal oxidizers are not recommended for halogenated VOCs or sulfur-containing gas streams because of the corrosive products (HCl, SO_2) that result unless there is an acid-gas scrubber downstream. This configuration may be uneconomic compared to other options.

Control Efficiency

The typical control efficiency range for VOCs is from 95 to >99 percent (EPA, 1991a). For pollutant concentrations between 20 and 100 ppmv, control efficiencies of 95 to 99 percent can be achieved. For concentrations above 100 ppmv, control efficiencies over 99 percent can be achieved. When treating very low pollutant concentrations (< 20 ppmv), control efficiencies may fall below 95 percent (EPA, 1991a).

Monitoring Parameters:

Combustion zone temperature, oxygen concentration, flue gas flow rate, auxiliary fuel supply rate, other specifications required by the equipment vendor, source-specific requirements by permit (e.g. inlet/outlet pollutant concentrations).

Record-Keeping Requirements:

Recording of continuous temperature readouts, oxygen concentration, flue gas flow rate, and auxiliary fuel supply rate; other specifications recommended by the equipment vendors; source-specific requirements by permit (e.g. inlet/outlet pollutant concentrations).

Dry Electrostatic Precipitator

An electrostatic precipitator (ESP) is a PM control device that uses electrical forces to move particles entrained within an exhaust stream onto collection surfaces (electrodes). In an ESP, an intense electric field is maintained between high-voltage discharge electrodes, typically wires or rigid frames, and grounded collecting electrodes, typically plates. An electric discharge from the discharge electrodes ionizes the gas passing through the ESP, and gas ions subsequently ionize particles in the gas stream. The electric field drives the negatively charged particles to the collecting electrodes. Because the collection forces act only on the particles, ESPs can treat large volumes of gas with low pressure drops. ESPs are broadly grouped into either dry or wet types depending on the method used to dislodge the collected particulate from collection surfaces.

The applicable EPA control device codes for this category are 010 (Electrostatic Precipitator - High Efficiency); 011 (Electrostatic Precipitator - Medium Efficiency); 012 (Electrostatic Precipitator - Low Efficiency); and 128 (Electrostatic Precipitator). Pechan assigned code 128 to dry ESPs. There are no EPA definitions for the three efficiency ranges assigned in the EPA table – High Efficiency, Medium Efficiency and Low Efficiency. Also, there are no data in the literature that allow for a distinction of dry ESPs by control efficiency level or specific design criteria from which control efficiency could be inferred.

Description

The most common ESP designs are wire-plate and wire-pipe collectors, but plate-plate and rigid frame-plate designs are also used. Collecting plates are arranged parallel to the gas flow, normally 9 to 18 inches apart, with discharge electrodes between them.

In a wire-pipe ESP, also called a tubular ESP, the exhaust gas flows vertically through conductive tubes, generally with many tubes operating in parallel. The tubes may be formed as a circular, square, or hexagonal honeycomb. Square and hexagonal pipes can be packed closer together than cylindrical pipes, reducing wasted space. Pipes are generally 7 to 30 cm (3 to 12 in) in diameter and 1 to 4 meters (3 to 12 ft) in length. The high voltage electrodes are long wires or rigid "masts" suspended from a frame in the upper part of the ESP that run through the axis of each tube. Rigid electrodes are generally supported by both an upper and lower frame. In modern designs, sharp points are added to the electrodes, either at the entrance to a tube or along the entire length in the form of stars, to provide additional ionization sites (EPA, 1998; EPA, 2003).

In the wire-plate ESP, the exhaust gas flows horizontally and parallel to vertical plates of sheet metal. Plate spacing is typically between 19 to 38 cm (9 in to 18 in; AWMA, 1992). The high voltage electrodes are long wires that are weighted and hung between the plates. Some later designs use rigid electrodes (hollow pipes approximately 25 mm to 40 mm in diameter) in place of wire (Cooper and Alley, 1994). Within each flow path, gas flow must pass each wire in sequence as it flows through the unit. The flow areas between the plates are called ducts. Duct heights are typically 6 to 14 meters (m; 20 to 45 feet; EPA, 1998).

Most ESPs have three to five independent electrical sections in series. Each independent section removes a fraction of the PM in the gas stream. This arrangement allows the use of higher voltages in the first sections of the ESP, where there is more PM to be removed. Lower voltages must be used in the final, cleaner ESP sections to avoid excessive sparking between the discharge and collecting electrodes (STAPPA/ALAPCO, 1996).

The power supplies for the ESP convert the industrial AC voltage (220 to 480 volts) to pulsating DC voltage in the range of 20,000 to 100,000 volts as needed. The voltage applied to the electrodes causes the gas between the electrodes to break down electrically, an action known as a "corona". The electrodes are usually given a negative polarity because a negative corona supports a higher voltage than does a positive corona before sparking occurs. The ions generated in the corona follow electric field lines from the wires to the collecting plates. Therefore, each wire establishes a charging zone through which the particles must pass. As larger particles (>10 μm diameter) absorb many times more ions than small particles (>1 μm diameter), the electrical forces are much stronger on the large particles (EPA, 1996a).

In a dry ESP, the collecting electrodes are mechanically rapped periodically to dislodge collected PM, which falls into hoppers for removal (STAPPA/ALAPCO, 1996). In more recent applications, dry ESPs have been cleaned acoustically with sonic horns (EPA, 2003). The horns, typically cast metal horn bells, are usually powered by compressed air. Acoustic vibration is introduced by a vibrating metal plate that periodically interrupts the airflow. As with a rapping system, the collected particulate slides downward into the hopper. The hopper is evacuated periodically, as it becomes full. Dust is removed through a valve into a dust-handling system, such as a pneumatic conveyor, and is then disposed of in an appropriate manner.

Application

Approximately 80 percent of all ESPs in the United States are used in the electric utility industry. Many ESPs are also used in pulp and paper (7 percent), cement and other minerals (3 percent), iron and steel (3 percent), and nonferrous metals (1 percent) industries (Cooper and Alley, 1994). The dust characteristics can be limiting factors in the applicability of dry ESPs to various industrial operations. Sticky or moist particles and mists can be easily collected but often prove difficult to remove from the collection electrodes of dry ESPs. Dusts with very high resistivities are also not well-suited for collection in dry ESPs. Dry ESPs are susceptible to explosion in applications where flammable or explosive dusts are found (McIlvaine, 1996).

ESPs are usually not suited for use in processes which are highly variable because frequent changes in operating conditions are likely to degrade ESP performance. ESPs are also difficult to install in sites which have limited space since ESPs must be relatively large to obtain the low gas velocities necessary for efficient PM collection (Cooper and Alley, 1994).

Control Efficiency

While several factors determine ESP collection efficiency, ESP size is most important. Size determines treatment time; the longer a particle spends in the ESP, the greater its chance of being collected. Maximizing electric field strength will maximize ESP collection efficiency (STAPPA/ALAPCO, 1996). The resistivity of the particles to be collected is also important. Resistivity is the resistance of particles to the flow of electric current. Particles with intermediate resistivities [10^7 to 10^{10} ohms per centimeter (cm)] are amenable to collection with ESPs; these particles are easy to charge and only slowly lose their charge once deposited on a collecting electrode (STAPPA/ALAPCO, 1996).

Factors limiting dry ESP performance include flow nonuniformity and dust re-entrainment, which may occur during rapping (STAPPA/ALAPCO, 1996). The particles re-entrained during rapping are then processed again by later ESP sections, but the particles re-entrained in the last section of the ESP escape the unit (AWMA, 1992).

AP-42 (EPA, 1995b) chapters were reviewed to identify particle size distribution profiles that could be used to calculate ESP control efficiencies for PM and the cumulative mass for particles ≤ 10 μm and ≤ 2.5 μm. For PM, the lowest control efficiency calculated was 95.00 percent. For PM10, the lowest control efficiency calculated was 89.76 percent. For PM2.5, the lowest control efficiencies calculated was 95.35 percent. Based on professional judgment, 90, 85, and 80 percent were selected to represent typical low-end control efficiency values for PM, PM10, and PM2.5, respectively. The control efficiency values calculated from the AP-42 particle size profiles are considered to be reliable because they have undergone peer review before publication. The low-end control efficiency values represent existing units that have been operating for several years and suffered slight deterioration in performance, or were installed to meet emission limits established several years ago that would be considered relatively lenient compared to current emission limits.

The highest PM control efficiency calculated was 99.89 percent. For PM10, the highest control efficiency calculated was 99.40 percent. For PM2.5, the highest control efficiency calculated was 99.35 percent. The high-end control efficiency values for PM, PM10, and PM2.5 selected were >99.9, 99.5, and >99.0 percent, respectively. The high-end of the ranges are based on the assumption that ESP design, operation, and maintenance technology has advanced over the past 20 years such that most types of ESPs could be designed to achieve these control efficiency levels. Given that the form of the PM NAAQS is now PM2.5 instead of PM10, it is assumed that vendors will be optimizing ESP systems to achieve high PM2.5 control efficiencies.

Monitoring Parameters

Flue gas temperature, **voltage, current**, PM loading, flue gas flow rate, conditioning agents if used

The electrical field, which is control by the combination of voltage and current, produces a force on particles to be removed from the gas. The motion of the particles under the influence of the electrical field is opposed by the viscous drag of the gas. The temperature of the flue gas directly affects the gas viscosity, which increases with temperature. Gas viscosity is affected to a lesser degree by the gas composition, particularly the water vapor content. The gas temperature and composition can have a strong effect on the resistivity of the collected particulate material. Specifically, moisture and acid-gas components may be chemisorbed on the particles in a sufficient amount to lower the intrinsic resistivity dramatically. Gas conditioning equipment to improve ESP performance by changing dust resistivity is occasionally used as part of the original design, but more frequently it is used to upgrade existing ESPs (EPA, 2003). The equipment injects an agent into the gas stream ahead of the ESP. Usually, the agent mixes with the particles and alters their resistivity to promote higher migration velocity, and thus higher collection efficiency. Conditioning agents that are used include SO_3, H_2SO_4, sodium compounds, ammonia, and water; the conditioning agent most used is SO_3 (AWMA, 1992).

Record-Keeping Requirements

Continuous recording of flue gas temperature, voltage, current, PM loading, and flue gas flow rate; daily recording of conditioning agent flow rate(s).

Fabric Filter (Pulse-jet, Reverse-air, Mechanical Shaker)

In a fabric filter, flue gas is passed through a tightly woven or felted fabric, causing PM in the flue gas to be collected on the fabric by sieving and other mechanisms (STAPPA/ALAPCO, 1996). Fabric filters may be in the form of sheets, cartridges, or bags, with a number of the individual fabric filter units housed together in a group. Bags are the most common type of fabric filter. The dust cake that forms on the filter from the collected PM can significantly increase collection efficiency. Fabric filters are frequently referred to as baghouses, because the fabric is usually configured in cylindrical bags. Bags may be 20 to 30 feet long and 5 to 12 inches in diameter. Groups of bags are placed in isolated compartments to allow cleaning of the bags or replacement of some of the bags without shutting down the entire fabric filter (STAPPA/ALAPCO, 1996).

Operating conditions are important determinants of the choice of fabric. Some fabrics (e.g., polyolefins, nylons, acrylics, polyesters) are useful only at relatively low temperatures of 200 to 300°F. For high-temperature flue gas streams, more thermally stable fabrics such as fiberglass, Teflon®, or Nomex® must be used (STAPPA/ALAPCO, 1996). Fabric filters are most commonly employed to control PM emissions; however they are sometimes used to control SO_2 emissions.

This category includes a group of devices. The applicable EPA control device codes for this category are 016 (Fabric Filter - High Velocity, I.E. T>250F); 017 (Fabric Filter - Medium Temperature, I.E. 180F<T<250F); 018 (Fabric Filter - Low Temperature, I.E. T<180F); 100 (Baghouse); 127 (Fabric Filter). The information on fabric filters in this section applies to all sources including metal fume sources. In the control device database, fabric filter applications to metal fume sources were listed separately from other applications in an attempt to distinguish the differing control efficiencies achieved (see discussion under control efficiencies below). Code 100 was assigned to applications other than metal fume sources, while code 127 was assigned to fabric filter applications to metal fume sources.

For PM Control

Description

The three major fabric filter types, classified by cleaning method, are mechanical shaker, reverse-air, and pulse-jet. Mechanical shaking has been a popular cleaning method for many years because of its simplicity as well as its effectiveness. In typical operation, dusty gas enters an inlet pipe to the shaker cleaned fabric filter and very large particles are removed from the stream when they strike the baffle plate in the inlet duct and fall into the hopper. The particulate-laden gas is drawn from beneath a cell plate in the floor and into the filter bags. The gas proceeds from the inside of the bags to the outside and through the outlet pipe. The particles are collected on the inside surface of the bags, and a filter cake accumulates. In mechanical shaking units, the tops of bags are attached to a shaker bar, which is moved briskly (usually in a horizontal direction) to clean the bags. The shaker bars are operated by mechanical motors or by hand, in applications where cleaning is not required frequently (EPA, 1998). The vibration cleaning method is similar to mechanical shaking units. It utilizes a pneumatically driven high frequency, low amplitude vibration of the bag frame to clean the bags. This method has limited application due to its low cleaning energy and smaller baghouse design (Billings, 1970).

Reverse-air cleaning is a popular fabric filter cleaning method that has been used extensively and improved over the years. It is a gentler but sometimes less effective cleaning mechanism than mechanical shaking. Most reverse-air fabric filters operate in a manner similar to shaker-cleaned fabric filters. In reverse-air units, the flue gas flows upward through the insides of vertical bags that open downward, fly ash collects on the insides of the bags, gas flow keeps the bags inflated, and cleaning is accomplished by reversing the gas flow (STAPPA/ALAPCO, 1996). However, some reverse-air designs collect dust on the outside of the bags. In either design, reverse-air cleaning is performed by forcing clean air through the filters in the opposite direction of the dusty gas flow. The change in direction of the gas flow causes the bag to flex and crack the filter cake. In internal cake collection, the bags are allowed to collapse to some extent during reverse-air cleaning. The bags are usually prevented from collapsing entirely by some kind of support, such as rings that are sewn into the bags. The support enables the dust cake to fall off the bags and into the hopper. Cake release is also aided by the reverse flow of the gas. Because felted fabrics retain dust more than woven fabrics and thus, are more difficult to clean, felts are usually not used in reverse-air systems (EPA, 1998).

There are several methods of reversing the flow through the filters. As with mechanical shaker-cleaned fabric filters, the most common approach is to have separate compartments within the fabric filter, so that each compartment can be isolated and cleaned separately while the other compartments continue to treat the dusty gas. One method of providing the reverse flow air is by the use of a secondary fan supplying cleaned gas from the other compartments. Reverse-air cleaning alone is used only in cases where the dust releases easily from the fabric. In many instances, reverse-air is used in conjunction with shaking, pulsing or sonic horns (EPA, 1998).

Sonic horns are increasingly being used to enhance the collection efficiency of mechanical shaker and reverse-air fabric filters. The horns are typically powered by compressed air, and acoustic vibration is introduced by a vibrating metal plate which periodically interrupts the gas flow (AWMA, 1992). The number of horns required is determined by the fabric area and the number of baghouse compartments. Sonic horns activate for approximately 10 to 30 seconds during each cleaning cycle. Sonic horn cleaning significantly reduces the residual dust load on the bags. This decreases the pressure drop across the filter fabric by 20 to 60 percent. It also lessens the mechanical stress on the bags, resulting in longer operational life (Carr, 1984).

Pulse-jet cleaned fabric filters are relatively new compared to other types of fabric filters, since they have only been used for the past 30 years. This cleaning mechanism has consistently grown in popularity, because it can treat high dust loadings, operate at constant pressure drop, and occupy less space than other types of fabric filters. Pulse-jet cleaned fabric filters can only operate as external cake collection devices. The bags are closed at the bottom, open at the top, and supported by internal retainers, called cages. Particulate-laden gas flows into the bag, with diffusers often used to prevent oversized particles from damaging the bags. The gas flows from the outside to the inside of the bags, and then out the gas exhaust. Dust is removed by a reverse pulse of high-pressure air. The particles collect on the outside of the bags and drop into a hopper below the fabric filter. (EPA, 1998, STAPPA/ALAPCO, 1996)

During pulse-jet cleaning, a short burst of high pressure air is injected into the bags (EPA, 1998; AWMA, 1992). The pulse is blown through a venturi nozzle at the top of the bags and establishes a shock wave that continues onto the bottom of the bag. The wave flexes the fabric, pushing it away from the cage, and then snaps it back dislodging the dust cake. The cleaning cycle is regulated by a remote timer connected to a solenoid valve. The burst of air is controlled by the solenoid valve and is released into blow pipes that have nozzles located above the bags. The bags are usually cleaned row by row (EPA, 1998).

There are several unique attributes of pulse-jet cleaning. Because the cleaning pulse is very brief, the flow of dusty gas does not have to be stopped during cleaning. The other bags continue to filter, taking on extra duty because of the bags being cleaned. In general, there is no change in fabric filter pressure drop or performance as a result of pulse-jet cleaning. This enables the pulse-jet fabric filters to operate on a continuous basis with solenoid valves as the only significant moving parts. Pulse-jet cleaning is also more intense and occurs with greater frequency than the other fabric filter cleaning methods. This intense cleaning dislodges nearly all of the dust cake each time the bag is pulsed. As a result, pulse-jet filters do not rely on a dust cake to provide filtration. Felted (non-woven) fabrics are used in pulse-jet fabric filters because they do not require a dust cake to achieve high collection efficiencies. It has been found that woven fabrics used with pulse-jet fabric filters leak a great deal of dust after they are cleaned (EPA, 1998).

Since bags cleaned by the pulse-jet method do not need to be isolated for cleaning, pulse-jet cleaned fabric filters do not need extra compartments to maintain adequate filtration during cleaning. Also, because of the intense and frequent nature of the cleaning, they can treat higher gas flow rates with higher dust loadings. Consequently, fabric filters cleaned by the pulse-jet method can be smaller than other types of fabric filters in the treatment of the same amount of gas and dust, making higher gas-to-cloth ratios achievable (EPA, 1998).

The advantages of fabric filters include very high collection efficiencies and the flexibility to treat may types of dusts and a wide range of volumetric gas flows. In addition, they can be operated with low pressure drops. Disadvantages of fabric filters are that, in general, fabric filters are limited to filtering dry streams; high temperatures and certain chemicals can damage some fabrics; there is a potential for fire or explosion; and they can require a large area for installation (AWMA, 1992).

Application

Fabric filters are useful for collecting particles with resistivities either too low or too high for collection with ESPs. The applicability of fabric filters is limited by the dust characteristics, as well as the potential for explosion, temperature, and humidity. Particles that are moist or very adhesive may present clogging problems.

Shaker-cleaned fabric filters are very flexible in design, allowing for different types of fabrics, bag arrangements, and fabric filter sizes. This enables shaker-cleaned fabric filters to have many applications with only some limitations (McIlvaine, 1996).

Reverse-air cleaning alone is used only in cases where the dust releases easily from the fabric, and in many instances, reverse-air is used with shaking or pulsing. Reverse-air cleaning with sonic assistance has become a very popular method for fabric filters at coal-burning utilities (Cooper and Alley, 1994).

Control Efficiency

Determinants of fabric filter performance include the fabric chosen, the cleaning frequency and methods, flue gas characteristics (e.g., temperature and moisture content), and particle size distribution. Fabric filters often are capable of 99.9 percent removal efficiencies and commonly can reduce utility boiler emissions to below 0.03 lb/MMBtu and often to below 0.01 lb/MMBtu. Fabric filter removal efficiency is relatively level across the particle size range, so that excellent control of PM10 and PM2.5 can be obtained (STAPPA/ALAPCO, 1996).

Cleaning intensity and frequency are important variables in determining removal efficiency. Because the dust cake can provide a significant fraction of the fine PM removal capability of a fabric, cleaning that is too frequent or too intense will lower the removal efficiency. If cleaning is too infrequent or too ineffective, the fabric filter pressure drop will become too high (STAPPA/ALAPCO, 1996).

AP-42 (EPA, 1995b) chapters were reviewed to identify particle size distribution profiles for fabric filters that could be used to calculate control efficiencies for PM and the cumulative mass for particles ≤ 10 µm and ≤ 2.5 µm. For PM, the lowest control efficiency calculated was 94.20 percent. For PM10, the lowest control efficiency calculated was 87.60 percent. For PM2.5, the lowest control efficiency calculated was 85.53 percent. Based on professional judgment, 90, 85, and 80 percent were selected to represent low-end control efficiency values for PM, PM10, and PM2.5, respectively. The control efficiency values calculated from the AP-42 particle size profiles are considered to be reliable, because they have undergone peer review before publication. The low-end control efficiency values represent existing units that have been operating for several years and suffered deterioration in performance or were installed to meet emission limits established several years ago that would be considered relatively lenient compared to current emission limits.

The highest control efficiency calculated from the profiles was 99.99 percent for both PM and PM10. For PM2.5, the highest control efficiency calculated was 99.92 percent. Based on these data, the high-end control efficiency values selected for PM, PM10, and PM2.5 were >99.9, >99.9, and 99.9 percent, respectively. Based on engineering judgment and information provided by EPA (1998), representative control efficiency values of 99.0, 98.0, and 97.0 were selected for PM, PM10, and PM2.5, respectively. A separate set of records were developed for control of metal fume at iron and steel production facilities. These are based on the EPA (1998) PM10 and PM2.5 control efficiencies of 93.9 and 93.4, respectively for gray iron cupolas.

For SOx Control

Description

Fabric filters remove dust from a gas stream by passing the stream through a porous fabric. Dust particles form a more-or-less porous cake on the surface of the fabric. It is normally this porous cake that actually does the filtration. While chiefly intended to remove particulates, such as fly ash, from a gas flow, fabric filters can also remove some SO_2 when used as part of a dry injection scrubbing system. The fabric filter provides a site for unreacted sorbent to have a "second chance" to adsorb any SO_2 which failed to react with injected sorbent in the ductwork leading to the filter. The manner in which the cake on the filter is removed is critical to filter operation. Removal of too much of the cake will result in dust and SO_2 leakage, while insufficient removal will result in an unacceptable pressure drop (Buonicore, 1992; EPA, 1981).

Application

Fabric filters are used as part of a dry sorbent injection system for control of SO_2 and sometimes mercury emissions from coal- or oil-fired boilers for utilities or industrial facilities.

Control Efficiency

The typical SO_2 control efficiency range is from 15 to 30 percent (Buonicore, 1992). Control efficiency varies depending upon the operating conditions of the dry scrubbing system or spray dryer, as well as those of the fabric filter.

Monitoring Parameters

Gas stream **pressure drop**, flow rate, **opacity**, temperature, and amount of dust removed from baghouse.

Determinants of baghouse performance include the fabric chosen, the cleaning frequency and methods, and the particulate characteristics. Fabrics can be chosen which will intercept a greater fraction of particulate, and some fabrics are coated with a membrane with very fine openings for enhanced removal of submicron particulate. Such fabrics tend to be more expensive. Cleaning intensity and frequency are important variables in determining removal efficiency. Because the dust cake can provide a significant fraction of the fine particulate removal capability of a fabric, cleaning which is too frequent or too intense will lower the removal efficiency. On the other hand, if removal is too infrequent or too ineffective, then the baghouse pressure drop will become too high (ICAC, 1999).

Record-Keeping Requirements

The following parameters should be monitored to show adherence to vendor specifications: monthly/quarterly cleaning intensity and frequency, dust removal; daily records of gas stream pressure drop, flow rate, opacity, and temperature.

Pressure drop is often the only parameter monitored in a baghouse (AWMA, 1992). Pressure drop data cannot be interpreted properly, unless the flow rate is known. A record of flow rate may be useful in identifying a developing leak in the ducting or in the baghouse itself. Opacity readings are useful for knowing any potential changes in exhaust gas composition. The quantity of dust removed from each baghouse compartment should be monitored and recorded. A significant change in dust quantity may be indicative of baghouse failure or of process changes.

Flameless Thermal Oxidation

Description

Flameless Thermal Oxidation (FTO) is used for destroying VOCs in process and waste stream off-gas treatment and in the treatment of VOCs and chlorinated volatile organic compounds (CVOCs) from off-gases from soil remediation. FTO uses a heated packed-bed reactor typically filled with inert ceramic pieces. Oxidation of organic compounds occurs in a uniform thermal reaction zone contained in the ceramic-matrix packed bed at temperatures of 1600 to 1850°F. The large thermal mass of inert ceramic matrix enables it to store or release large amounts of heat without causing rapid changes in temperature and provides flame suppression within the reactor.

There is no applicable EPA control device code for this device. Thus, Pechan assigned a new code 511 to this device.

Application

FTO is applicable in the treatment of VOC off-gases from manufacturing and remediation processes. In large scale operations with CVOCs, a caustic scrubber should be placed in series to remove HCl gas.

Control Efficiency

The typical control efficiency range is from 99 to >99 percent (DOE, 1995; Hohl and Baer, 1997). During full-scale demonstration testing at the United State's Department of Energy's (DOE's) Savannah River Site (soil remediation) in 1995, DRE of> 99.995 percent was achieved for perchloroethylene (PCE) and >99.95 percent for trichloroethylene (TCE) and total CVOCs during continuous testing phase of the 22-day demonstration (DOE, 1995).

Low NOx (typically <2 ppmv) and low CO are produced due to the relatively low, steady oxidation temperature (DOE, 1995).

Monitoring Parameters:

These include **chamber temperature** and residence time or outlet VOC concentration.

Record-Keeping Requirements:

Continuous recording or hourly recording of chamber temperature and residence time or outlet VOC conc.

Flaring

Description

A flare is a direct combustion device in which air and all the combustible waste gases react at an external burner. Complete combustion must occur immediately, since there is no combustion chamber to provide any significant residence time. In a flare configuration, flame temperature is the primary variable in the destruction of waste gases.

Typically, large open flares are elevated to insure sufficient dilution and dispersion of the exhaust gases. In these cases, the organic-laden gas is fed to and discharged from an elevated stack, with combustion, characterized by a flame, occurring near the top. The discharge temperature is typically in the range of 1500 to 3000°F. Enclosed (ground) flares are composed of multiple gas burner heads at ground level in a stack-like enclosure that is usually refractory lined.

Adequate air supply and mixing are required for complete combustion and minimal smoke. The various flare configurations differ in their means of accomplishing adequate mixing (EPA, 2000). Flare configurations may include steam-assisted, air-assisted, non-assisted, and pressure head flares, all designed to improve combustion and limit smoke. The predominant type of flare is the steam-assisted flare. This type of flare uses steam injected into the combustion zone to promote turbulence for mixing. Air-assisted flares are built with a spider-shaped burner (with many small orifices) above a steel cylinder. A fan in the bottom of the cylinder provides combustion air. The non-assisted flare has no auxiliary provision for enhanced mixing, and is limited to use with gas streams that have a low heat content and a low carbon/hydrogen ratio. Pressure head flares use the vent stream pressure to promote mixing (EPA, 2000).

The applicable EPA control device code for this device is 023 (Flaring).

Application

A flare may be used when the concentration of organics in air exceeds the lower flammability level. Flares are used primarily in the petroleum and petrochemical industries for destroying VOCs during normal operation, process upsets (e.g., start-up and shutdown), and emergencies. They are designed to handle large fluctuations in flow rate, VOC content, inert material content and heating value. Flaring can be used for batch, continuous, and variable flow vent stream applications (EPA, 2000). Flaring is considered a good control option when the heating value of an emission stream cannot be recovered because of uncertain or intermittent flow. Flares are intended for nonhalogenated VOC emission streams, but are also used for emission streams with halogenated compounds (e.g. landfill gas). Flaring of halogenated or sulfur containing compounds can cause corrosion of the flare tip or formation of secondary pollutants. Auxiliary fuel may be required if the waste gas does not have sufficient heating value to sustain combustion.

Many flare systems are operated in conjunction with baseload gas recovery systems, which recover and compress the waste VOC for use as fuel or feedstock in other processes. In these cases, the flare is used in a backup capacity and for emergency releases (e.g. landfill gas energy plants). These systems can have a considerable economic advantage over a flare alone, depending on the quantity of usable VOC that can be recovered (EPA, 2000).

Control Efficiency

The typical control efficiency range for VOCs is between 98 and >99 percent (AWMA, 1992). A blue flame indicates good combustion and high efficiency of destruction. A yellow-orange flame with a trail of black smoke may occur during upset conditions and is a sign of incomplete combustion and lower destruction efficiency.

Monitoring Parameters:

Parameters include: **combustion zone temperature indicating presence of a flame**, fuel flow rate, heat content, pollutant concentrations in the fuel and exhaust, and other parameters based on manufacturer's specifications.

Record-Keeping Requirements:

These include continuous combustion zone temperature readings, fuel flow rates, heat content, flare inlet and outlet pollutant concentrations (as required by permit), and other specifications required by the vendor for specific applications.

Fluidized Bed Dry Scrubber

Description

Fluidized bed dry scrubbers are used in the primary aluminum manufacturing industry to control PM emissions from pot rooms and anode bake furnaces. The PM emissions consist of gaseous and particulate fluoride, carbon dust, and alumina. Alumina is used to scrub the gaseous fluoride emissions and the alumina containing fluoride is fed to manufacturing process. The dry scrubbing system consists of a fluidized bed reactor with a fabric filter located on top of the reactor. The potroom gases containing fluoride are reacted with alumina in the reactor and then passed through the fabric filter. The fabric filter captures and returns the entrained alumina particles to the reactor, as well as particulate fluoride and carbon particles produced by the cells in the potroom. Most of the fabric filters used are of the mechanical-shaker type; however, pulse-jet fabric filters have also been used (AWMA, 1992).

The applicable EPA control device codes for this category are 071 (Fluid Bed Dry Scrubber), 098 (Moving Bed Dry Scrubber), 119 (Dry Scrubber), and 120 (Floating Bed Scrubber).

Application

Fluidized bed dry scrubbers are used exclusively to control PM, fluoride, and hydrocarbon emissions from potroom prebake cells and anode baking furnaces in the manufacture of primary aluminum.

Control Efficiency

According to AWMA (1992), fluidized bed dry scrubber systems can achieve over 99 percent control of PM and fluoride emissions from potroom prebake cells and anode baking furnaces. PM emissions consists of gaseous and particulate fluoride, carbon dust, and alumina. Based on professional judgment, the control efficiency ranges for PM, PM10, and PM2.5 were assumed to be the same as those specified for fabric filters.

According to AWMA (1992), these systems can achieve 90 percent control of hydrocarbon emissions from anode baking furnaces. Therefore, 90 percent was selected to represent the high-end control efficiency. Based on professional judgment, 80 percent was selected as the low-end control efficiency to represent control levels associated with malfunctions or process upsets.

Monitoring Parameters:

Pressure drop was the only parameter identified.

Record-Keeping:

Record pressure drop every 24 hours to show adherence to vendor specifications.

Fluidized Bed Catalytic Incineration

Description

Fluidized bed catalytic incineration (FBCI) operates on a similar principle as the catalytic incinerator with a fixed bed, except the catalyst is in the form of small beads, through which the gas passes in an upward direction, then on to the burner/combustion chamber. A heat exchanger is usually incorporated into the design to recover heat from the exhaust gas prior to being vented to the atmosphere.

With the use of certain proprietary metal catalysts, the FBCI has been shown to be effective on both VOCs and CVOCs. Certain manufacturers also claim that their catalyst is not poisoned by lead, iron, zinc, or other metallic vapors (U.S. Filter, 1997).

Fluid-beds have the advantage of very high mass transfer rates. Also, the high heat transfer rate allows waste gas with higher heating values to be process without exceeding maximum temperatures in the catalyst bed.

Generally, fluid-beds are more tolerant of particulates than fixed-bed catalysts, because the constant abrasion of the beads continuously removes particles from the exterior of the catalyst. This abrasion, however, has the disadvantage of gradual loss of catalyst by attrition. Attrition-resistant catalysts have been developed (EPA, 2002).

There is no applicable EPA control device code for this device. Thus, Pechan assigned a new code 512 to this device.

Application

This control is used in most industries where VOCs and CVOCs are a problem -- adhesive coating, chemical processing, hydrocarbon processing, loading, unloading, paint finishing, pharmaceutical, printing, roasters, sheet/coil coating, soil/groundwater remediation, and wood furniture finishing.

Control Efficiency

The typical control efficiency range is from 70 to >99 percent. Pilot plant tests on several inlet gas mixtures indicate control efficiencies tend to be at the lower end of the range for CVOCs and at the higher end of the range for VOCs. Efficiencies tended to be higher at higher oxidation temperatures (approximately 950°F) than at lower oxidation temperatures (650°F). The destruction efficiency was found to be independent of the inlet concentration (RTI, 1995).

Monitoring Parameters:

Combustion temperature or inlet and outlet temperatures; and catalyst bed reactivity as per manufacturer's specifications; residence time, adequate oxygen

Record-Keeping Requirements:

Continuous recording or hourly recording of combustion temperature or inlet and outlet temperatures; and catalyst bed reactivity as per manufacturer's specifications; residence time, adequate oxygen.

Gravel Bed Filter

Description

The gravel-bed filter consists of several cylindrical compartments. Each compartment consists of quartz granules of about 2 to 5 millimeters in diameter lying on a wire mesh. As dirty gases are drawn through the beds, the dust drops out of the gas stream and remains in the bed. The beds are individually cleaned at regular intervals by reversing the airflow and agitating the gravel with an internal rake system. The gravel-bed filter is somewhat sensitive to flow volume changes that tend to result in PM emissions that are higher than normal (AWMA, 1992).

The applicable EPA control device code for this device is 063 (Gravel Bed Filter).

Application

Gravel-bed filters were developed for use in controlling emissions from kilns used to manufacture cement. However, they have been applied in other industries (e.g. ferroalloy production, ceramic clay manufacturing, and stone quarrying and processing) to control PM emissions from high-temperature flue gas streams. The advantage of the gravel-bed filter relative to a fabric filter is its ability to tolerate high-temperature gas temperatures, or high-temperature excursions, without permanent damage to the filter media (AWMA, 1992).

Control Efficiency

Published PM, PM10, and PM2.5 control efficiency data for existing gravel-bed filters are limited for determining low-end control efficiencies. When EPA developed the NEDS in the early 1970s [(predecessor to the Aerometric Information Retrieval System/ Facility Subsystem (AIRS/FS)], it prepared control equipment codes for use in defining control equipment types in the point source emissions inventory. The average overall PM control efficiency for the control equipment in a given industry is summarized in EPA (1973). The control efficiency data were obtained from technical background information documents and published articles. The PM control efficiencies reported in EPA (1973) are listed as follows by industry:

- 98.2 percent - ferroalloy production (open furnace);
- 99.1 percent - ceramic clay manufacturing (dryer);
- 99.2 percent - stone quarrying and processing (crushing and screening);
- 99.6 percent - dry cement production (clinker cooler); and
- 99.8 percent - wet cement production (dryers and grinders).

State submitted fabric filter PM control efficiencies for point sources contained in EPA's AIRS/FS database ranged from about 90.0 to 99.8 percent. Based on the data from these two information sources, 90.0 and >99.5 percent were selected to represent the PM control efficiency for gravel-bed filters. No control efficiency data could be identified for PM10 and PM2.5. The high-end control efficiency value for PM10 and PM2.5 was assumed to be 99 percent. The low-end control efficiency values for PM10 and PM2.5 were assumed to be 85 and 80 percent, respectively.

Monitoring Parameters:

Pressure drop is the only monitoring parameter identified.

Record-Keeping:

Daily recording of pressure drop to demonstrate adherence to vendor specifications.

Gravel Bed Moving Filter and Gravel Bed Moving Filter - Electrostatically Augmented

Description

An alternative design of the gravel-bed filter involves the use of a slow moving bed of granular rock as the filtration medium. Gravel is held between front and rear louver sets to form the filter bed. The louver structure provides large, nonfouling passages for the gas while retaining gravel by its angle of repose. The gravel is removed from the filter bed and cleaned externally in a pneumatic conveyor on a continuous basis. The dust removed from the gravel is conveyed to a small pulse-jet fabric filter, and the cleaned gravel is returned to the filter bed. Gravel-bed moving filters are also called granular-bed moving filters (AWMA, 1992).

To enhance efficiency, gravel-bed moving filters can be electrostatically augmented (10 to 20 watts/1,000 actual cfm of flue gas flow). Prior to entering the filter bed, the gas stream is ionized to impart a negative charge on particles in the gas stream. Gravel-bed moving filters are also called electrostatically augmented granular-bed moving filters or electrified filter beds (EPA, 1989).

There has no applicable EPA control device code for this category. Thus, Pechan assigned a new code of 520 to the Gravel Bed Moving Filter and a new code of 505 to the Gravel Bed Moving Filter – Electrostatically Augmented.

Application

Gravel-bed moving filters have been designed to remove PM emissions from high-temperature gas streams to eliminate the potential for fire hazard associated with the use of fabric filters, and they are designed to remove PM emissions from gas streams with a high moisture content that otherwise would foul and corrode a fabric filter. In addition, the filters collect fine PM that would otherwise require the use of a high-pressure drop scrubber (AWMA, 1992; EPA, 1989). Gravel-bed moving filters are most frequently used to control emissions from oriented strand board, particleboard, chipboard, plywood veneer dryers in the waferboard manufacturing industry, but also have been applied to control PM emissions from wood/bark waste fired boilers, coal fired boilers, asphalt saturators, polyethylene and polyvinyl chloride curing ovens, silicone rubber curing ovens, glass bubble formers, hospital and municipal solid waste incinerators. They have also been applied to control PM emissions from sources in the metal polishing, brass smelting, aluminum production, fiberglass curing, and plastics industries (EPA, 1989).

Control Efficiency

According to AWMA (1992), gravel-bed moving filters can achieve PM control efficiencies ranging from 90 to 95 percent for a new wood waste fired boiler that must meet a 0.1 lb/MMBtu PM emission limit. Electrostatically augmented gravel-bed moving filters can achieve PM control efficiencies ranging from 98 to 99.2 percent for a new wood waste fired boiler that must meet a 0.1 lb/MMBtu PM emission limit. According to EPA (1989), PM control efficiencies for electrostatically augmented gravel-bed moving filters range from 79 to 94 percent based on test data obtained for units used to control dryers in the waferboard industry.

The low-end of the PM control efficiency range for gravel-bed moving filters with and without electrostatic augmentation is assumed to be 80 percent based on the range of control efficiencies presented in EPA (1989). The high-end of the PM range for gravel-bed moving filters without electrostatic augmentation is estimated at 95 percent based on data presented in AWMA (1992). The high-end of the PM range for gravel-bed moving filters with electrostatic augmentation is estimated at >99.0 percent based on data presented in AWMA (1992).

No data were identified to determine control efficiency ranges for PM10 or PM2.5, but the low end of the PM10 control efficiency range is estimated to be 70 percent, the high end of the PM10 range for gravel-bed moving filters without electrostatic augmentation is estimated at 90 percent, and the high-end of the PM10 range for gravel-bed moving filters with electrostatic augmentation is estimated at 95.0 percent, based on professional judgment.

Monitoring Parameters:

Pressure drop.

Record Keeping Requirements:

Record pressure drop every 24 hours or in accordance with vendor specifications.

Gravity Collector (Expansion Chamber, Settling Chamber, Elutriators)

Description

Gravity collectors, also called gravity settling chambers or settling chambers, are add-on control devices that rely on gravity as the mechanism for removing large particles from a gas stream. There are three general types of settling chambers -- the expansion chamber, multiple-tray settling chamber, and elutriator. Settling chambers are designed for low velocities with a minimum of turbulence so that the settling of particles is not re-entrained in the gas stream exiting the device. To prevent reentrainment, uniform gas stream distribution across the chamber inlet is important. Typical superficial velocities range from 0.3 to 3 meters per second (EPA, 1982).

In the 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. Expansion chambers are most effective for controlling large and/or dense particles. The efficiency of gravity chambers increases with the residence time of gas in the chamber. Therefore, they are designed to operate at the lowest possible gas velocity to prevent dust from becoming reentrained but not so low that the chamber is unreasonably large.

A multiple-tray settling chamber is an expansion chamber with a number of thin trays closely spaced horizontally within the chamber. The trays act as collection plates that reduce the distance a particle must fall to reach the collection surface. Because small particles settle more slowly than large particles, trays are included in a settling chamber to improve the collection of small particles by decreasing the particle settling distance. In both types of settling chambers, the particles settle into collection hoppers at the base of the chamber which are cleaned periodically (EPA, 1982).

The elutriator consists of one or more vertical tubes or towers. The gas stream is passed upward through a tube, allowing particles with terminal settling velocities greater than the upward gas velocity to settle and collect at the bottom of each tube. Removal of different size classifications of particles can be achieved by using a series of tubes with different diameters. The gas stream is passed through the small diameter tube first to collect the largest particles and then through tubes with larger diameters to allow the smaller particles to settle out (EPA, 1982).

The applicable EPA control device codes for this category are 004 (Gravity Collector - High Efficiency); 005 (Gravity Collector - Medium Efficiency); and 006 (Gravity Collector - Low Efficiency). Pechan has combined all the three types – High Efficiency, Medium Efficiency and Low Efficiency Gravity Collectors into one description because the efficiency difference between high, medium and low Gravity Collectors isn't clearly defined by EPA, nor are there any data in the literature that allow for a distinction of Gravity Collectors by control efficiency level or specific design criteria from which control efficiency could be inferred.

Application

Mechanical collectors are used on a wide variety of processes in many different industries. According to one reference, elutriators are typically used to control PM emissions from secondary metal operations, food and agricultural processes, and processes in the petrochemical industry (EPA, 1982).

Control Efficiency

Mechanical collectors are most effective for controlling large and/or dense particles. The efficiency of mechanical collectors decreases as particle size decreases.

EPA (1982) presents fractional collection efficiencies based on a number of studies on high density iron oxide particles and low-density quartz dust particles. Based on this data, it is concluded that overall control efficiencies would range from 10 to 99 percent depending on the size of particles to be controlled. The low-end of the range applies to gas streams with a high concentration of particles with diameters ranging from 10 to 40 µm, and the high-end of the range applies to gas streams with a high concentration of particles with diameters 90 µm. The control efficiencies for mechanical collectors is minimal for particle sizes 10 µm. Thus, PM10 and PM2.5 control efficiencies for mechanical collectors is assumed to be zero percent.

Monitoring Parameters:

The only parameter identified was gas stream velocity.

Record Keeping Requirements:

Daily recording of gas stream velocity to show adherence to vendor specifications.

High Energy Corona

Description

High energy corona is one type of non-thermal plasma system. The high energy corona (HEC) process uses high-voltage electricity to destroy VOCs at room temperature. The primary system components are an HEC reactor, in which VOCs are destroyed, and a secondary scrubber. The reactor is a glass tube filled with glass beads through which pretreated contaminated off gas is passed. The demonstration reactors are two inches in diameter and four feet long. A high voltage electrode is placed along the centerline of the reactor, and a grounded metal screen is attached to the outer glass surface of the reactor. A high voltage power supply is connected across the electrodes to provide up to 50 milliamps of 60-hertz electricity at 30 kilovolts. The electrode current and power settings depend on the type and concentration of the contaminant. The prototype system contains 21 reactors. Each reactor can process up to 5 scfm of soil off-gas (FRTR, 1995).

The HEC system is packaged in a self-contained mobile trailer that includes gas handling equipment and on-line analytical capabilities.

There is no applicable EPA control device code for this device. Thus, Pechan assigned a new code 513 to this device.

Application

HEC technology is being developed by DOE as one of several approaches for decontaminating soil off-gasses produced during soil treatment operations. Contaminants treated include most VOCs and semi-volatile VOCs (SVOCs). The technique has been proven useful for CVOCs such as TCE, PCE, carbon tetrachloride, chloroform, and diesel fuel and gasoline. Both gas and liquid phase contaminants are treatable (FRTR, 1995).

When CVOCs are treated, the reactor effluent is scrubbed with a solution of either sodium hydroxide or baking soda to remove acid gases, HCl, and chlorine.

Control Efficiency

The typical control efficiency range for VOCs is from 90 to >99 percent. Field test data indicate destruction of 99.9 percent of TCE and 90 to 95 percent of PCE.

Monitoring Parameters:

Electrical values (voltage, current).

Record Keeping Requirements

Continuous recording of electrical values (voltage, current).

Mat or Panel Filter – Conventional and High Efficiency

Description

Conventional mat or panel filters are used to remove paint particles from the air in paint spray booths. Emissions of paint particles result from the use of air atomization spray guns (EPA, 1973a). Paint that is not deposited on the substrate being painted is called overspray. The amount of overspray depends on the shape of the substrate, the type of spray gun used, the solids content of the paint, and the experience of the spray gun operator. Overspray is lowest for flat surfaces and higher for irregular surfaces. Electrostatic spraying also decreases overspray.

Mat or panel filters are similar to air filters used in heating and air conditioning systems. Each unit consists of a rigid frame and a pad of filter material. Filters are classified as either viscous or dry. Viscous filters are coated with a viscous material such as an oil with a high flash point and low volatility to help catch dust and prevent dust reentrainment. A ventilation system is used to draw air through mat or panel filters located at the back of the paint booth to remove PM emissions. Filter materials used include glass fibers, hemp fibers, corrugated fiberboard, split wire, or metal screening. Viscous filters can be operated at air velocities ranging from 300 to 500 feet per minute. Dirty filters can be disposed of or washed or steamed clean, reoiled, and replaced (EPA, 1973a).

Dry filters are supplied in units similar to viscous filters, except that the depth is usually greater. The filter materials usually have smaller air passages than the viscous filters, and, therefore, lower air velocities must be used to prevent excessive pressure drop. Dry filters can be operated at air velocities ranging from 30 to 60 feet per minute. To increase the filtering area, the filter pads are often arranged in an accordion form with pleats and pockets. Dirty dry filters are disposed because they cannot be cleaned and reused (EPA, 1973a).

High efficiency filters are generally referred to High Efficiency Particle Air (HEPA) and/or Ultra Low Penetration Air (ULPA) filters (also referred to as Extended Media). HEPA and ULPA filters are best applied in situations where high collection efficiency of submicron PM is required, where toxic and/or hazardous PM cannot be cleaned from conventional filters. Generally, the filter media is fabricated of matted glass fiber such as borosilicate microfiber. The small fiber diameter and high packing density of both the paper and nonwoven media allow for the efficient collection of submicron PM.

The high efficiency filters are typically utilized for applications involving chemical, biological, welding fumes, and radioactive PM. HEPA and ULPA filters are installed as the final component in a PM collection system, downstream from other PM collection devices such as ESPs or baghouses (EPA, 2003).

The applicable EPA control device code for the Conventional Mat or Panel Filter is 058. 101 will be the applicable code from EPA for the Mat or Panel Filter with high efficiency, such as HEPA and ULPA.

Application

Dry filters are frequently used in paint spray booths to control PM emissions. A common industrial application of the wire screen-type filter is in collection of mist generated from cutting oils used by metal-cutting machines.

Common industrial applications of HEPA and ULPA filters are hospital, low-level nuclear mixed waste incinerators, clean rooms, pharmaceutical manufacturing, and welding fumes.

Control Efficiency

According to American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE, 1999), mat or panel filters can control paint particles as high as 98 percent. Typical ranges of control efficiencies are listed as follows (the filter types and typical applications are shown in parentheses):

- 60 percent - 80 percent for PM > 10 μm (disposable fiberglass, latex coated/synthetic/foam panel filter; residential, minimum filtration, air conditioners, spray paint dust)
- 80 percent - 90 percent for PM10 (disposable fiberglass, latex coated/synthetic/foam panel filter; paint booth, food industry, cement dust)
- 98 percent - 99 percent for PM2.5 (microfine fiberglass or synthetic media pocket filters, extended rigid cell filters; welding fumes, hospitals, laboratories, milled flour, lead dust)
- >99.97 percent for submicron PM (HEPA/ULPA filters; pharmaceutical manufacturing, hospitals, paint pigments, combustion smoke)

Monitoring Parameters:

Condition of the filters, including, but not limited to, alignment, saturation, and tears and holes; **opacity**, temperature.

Opacity is practically used to instantly/automatically detect ruptures in mat and panel filters. Holes in filters do not change pressure drop noticeably but can significantly reduce PM control efficiency through bypassing. When opacity increases and/or suddenly showing higher than normal, it is a sign for maintenance, which includes alignment, saturation, and holes.

Record Keeping Requirements:

Daily record of filter(s) condition; daily opacity and temperature.

Mechanically-Aided Scrubber

Description

In a mechanically-aided scrubber, droplet dispersion for enhanced PM control is created 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 the system to break the liquid into fine droplets. The mechanically driven device acts on both the liquid and the gas (AWMA, 1992). As in other types of scrubbers, it is the droplets that are the principal collecting bodies for the dust particles. Mechanically-aided scrubbers have also been referred to as wet dynamic separators.

The applicable EPA control device codes for this category are 057 (Dynamic Separator (Wet)) and 085 (Wet Cyclonic Separator).

Application

Mechanically-aided wet scrubbers have been used in the following industries to control PM emissions: metal can fabrication, phosphate rock processing, starch manufacturing, and asphaltic concrete manufacturing (EPA, 1973b).

Control Efficiency

Published PM, PM10, and PM2.5 control efficiency data for determining low-end control efficiencies for existing mechanically-aided scrubber are limited. PM control efficiencies reported in EPA (1973b) are listed as follows by industry (the process type on which the scrubbers were used is shown in parentheses):

- 96 percent - phosphate rock processing (grinding);
- 97.5 percent - starch manufacturing (general);
- 99 percent - metal can fabrication (spray coating);
- 99 percent - phosphate rock processing (transfer and storage); and
- 99.9 percent - asphaltic concrete manufacturing (rotary dryer).

Based on these data, >99 percent was selected to represent the high-end PM control efficiency for mechanically-aided wet scrubbers. The low-end PM control efficiency (i.e., 70 percent) was based on that for spray chamber wet scrubbers to represent existing units that have been operating several years and suffered deterioration in performance or were installed to meet emission limits established several years ago that would be considered relatively lenient as compared to current emission limits.

No control efficiency data could be identified for PM10 and PM2.5. The PM10 control efficiency values were assumed to be the same as that for PM. For PM2.5, the range is based on the control efficiency range discussed for the "scrubber (general, not classified)" control equipment code.

Monitoring Parameters:

Pressure drop and water supply.

Pressure drop is an important parameter, because it relates directly to operating costs and control efficiency. Since it is the droplets that are the principal collecting bodies for the dust particles, water supply rate is recommended to be monitored to ensure the device generate enough water droplets.

Record-Keeping Requirements:

Recording of pressure drop and water supply rate.

Mechanically-Aided Separator

Description

Mechanically-aided separators are add-on control devices that rely on inertia as the mechanism for separating particles from a gas stream. They are also called centrifugal collectors or separators, dry dynamic separators, or dry rotoclones. These devices involve the use of a rotary vane (e.g., radial blade fan) to mechanically impart a centrifugal force on the particles in the gas stream causing them to separate from the gas stream. The particles are collected in a dust hopper for removal and disposal. The most common design is a modified radial blade fan where the particulate laden gas stream enters the device perpendicular to the blade rotation, and momentum forces the particles to cross the gas stream and collect in the side of the collector casing. The rapid acceleration of the gas stream imparted by the rotation of the blades maintains the concentrated particles in a narrow band which is then drawn off for particle separation in a more efficient collector. Many collectors use this design principle to concentrate particles into a smaller gas volume (EPA, 1982).

This category includes several devices. The applicable EPA control device codes for this category are 056 (Dynamic Separator (Dry)) and 113 (Rotoclone).

Application

Mechanically-aided separators are used to control PM, and primarily PM greater than 8 to 10 micrometers (μm) in aerodynamic diameter (EPA, 2003).

Mechanically-aided separators are compact and are particularly useful where a large number of individual collectors are required. These devices generally cannot be used to collect particles that cake or tend to accumulate on the rotary vane or blades causing clogging or unbalancing of the blades. Also, they are subject to abrasion by the action of large-diameter particles at medium to high velocities (EPA, 1982).

Control Efficiency

EPA (1982) presents theoretical fractional collection efficiency curves for two types of centrifugal collectors. The fractional efficiency curve for one type is very similar to that discussed for momentum separators. The fractional efficiency curve for the other type is significantly below that discussed for momentum separators. As a result of a lack of control efficiency data for centrifugal collectors, the control efficiency ranges for this type of control were assumed to be the same as those for momentum separators.

The collection efficiency associated with a mechanically-aided separator is comparable with a high-pressure-drop cyclone. Mechanically-aided separators are capable of collection efficiencies approaching 30 percent for PM10 (Perry and Green, 1984; EPA, 1998).

Monitoring Parameters

Gas stream velocity and or pressure drop. Pressure drop is an important parameter, because it relates directly to operating costs and control efficiency. Higher control efficiencies for a given cyclone can be obtained by higher inlet velocities, but this also increases the pressure drop.

Record-Keeping

Daily recording of gas stream velocity and/or pressure drop.

Mist Eliminator - Blade-Type

Description

Blade-type mist eliminators consist of one or more sets of parallel, chevron-shaped baffles (blades) arranged in a horizontal-flow configuration. Each blade changes the direction of the gas flow four times, which causes droplets to impinge on the surface of the blades as a result of inertial force. Water sprays mounted at the inlet of the mist eliminator and directed toward the blades are activated periodically to wash the blades. For units used to control mist from chromium electroplating and chromic acid anodizing tanks, the wash water is drained to the plating tank to make up for evaporative losses of plating solution and to recover chromic acid. Otherwise, the wash water is drained to a wastewater treatment system (EPA, 1993a).

Two blade designs commonly used are overlapping and sinusoidal wave. The overlapping design consists of a set of blades with overlapping edges. In contrast, the sinusoidal wave design consists of a set of blades with rounded edges and catchments located between the rounded edges. The overlapping edges, or catchments, act as collection troughs for droplets and facilitate drainage of the droplets into a collection sump. Blades typically range from 15 to 30 cm (6 to 12 inches) in depth. The spacing between blades may vary but is normally 3.18 cm (1.25 inches) (EPA, 1993a).

The applicable EPA control device codes for this category are 014 (Mist Eliminator - High Velocity, I.E. V>250 FT/MIN), 015 (Mist Eliminator - Low Velocity, I.E. V<250 FT/MIN), 134 (Demister), 151 (Fiber Mist Eliminator), and 152 (Mist Eliminator - High Efficiency). Pechan selected code 015 as the MPCA code for this device type, although this device type is not limited to low velocity applications.

Application

Blade-type mist eliminators are most frequently used in scrubbers to eliminate mist from carrying pollutants out the stack of the scrubbers; however, they can also be used as stand-alone control devices to control acid mists. Horizontal-flow chevron-blade mist eliminators typically are used to control chromic acid mist because the horizontal-flow configuration is more effective than the vertical-flow configuration for the high inlet velocities and pollutant loadings common for chromium plating operations (EPA, 1993a).

Control Efficiency

Major factors that affect the performance of chevron-blade mist eliminators include the face velocity of the gas stream across the blades, the spacing between blades, and the tightness of seals between the blades and the walls of the unit. Gas stream velocities must be maintained within design specifications to maximize the operating efficiency of the unit. Gas velocities less than the specified minimum will not provide the inertial force required to maximize impingement of chromic acid droplets on the blades, and gas velocities greater than the specified maximum may cause droplets to become reentrained in the gas stream.

EPA (1993a) provides control efficiency data for chevron-blade mist eliminators used to control chromic acid mist from hexavalent chromium electroplating baths. For test conducted on three chevron-blade mist eliminators at three separate plants, average control efficiencies ranged from 87.9 to 98.4 percent for chromic acid mist. All three of these mist eliminators are stand-alone units that are used as the primary control device to control acid mist. Control device vendors estimate that removal efficiencies range from 80 to 90 percent (EPA, 1993a). Control efficiency data for PM10 and PM2.5 could not be identified. Based on professional judgment, PM10 control efficiencies were assumed to be the same as the range for PM control efficiencies. PM2.5 control efficiencies were estimated to range from 50.0 to 70.0 percent. These control efficiency ranges are for stand-alone units that are used as the primary control device.

Monitoring Parameters:

If not used as part of larger control system (e.g. on top of scrubber), **quarterly visual checks on blades and seals.**

Record Keeping Requirements:

Quarterly visual checks on blades and seals.

Mist Eliminator - Mesh-Type

Description

Mesh-pad mist eliminators consist of layers of interlocked filaments densely packed between two supporting grids. The principal control mechanisms are inertial impaction and direct interception. Inertial impaction occurs when particles larger than about 3 μm (0.12 million), traveling with sufficient velocity, collide with the filaments and adhere to their surface. Other particles, because of their size and relative velocity, are intercepted by the fluid layer surrounding the surface of the filament. Collected liquid droplets flow along the fibers to a point where adjacent filaments cross. These crossover points rapidly become loaded with liquid, and droplets drain to the bottom of the mist eliminator as a result of gravity (EPA, 1993a).

The mesh pads consist of thin, multiple layers of interwoven fibers. These layers are compacted and fastened together with thin filaments. Pad thicknesses vary from 10 to 15 cm (4 to 6 inches), but occasionally pads as thick as 30.5 cm (12 inches) are used. Often two mesh-type separators in series are used to remove particles in the 1 to 5 μm (0.04 to 0.20 million) diameter range. The first mesh, normally made of fine fibers, coalesces the small drops, and the second mesh, made of standard fibers, removes them (EPA, 1993a).

In recent years, mesh-pad mist eliminators equipped with internal spray systems to clean the pads have been developed, avoiding potential plugging problems. These newer units contain multiple mesh pads in series that are designed to remove chromic acid mist in stages. The first stage removes the bulk of the mist, which is comprised of fairly large particles (>5 μm), and the second stage removes the smaller particles (3 to 5 μm). Because the internal spray system protects the pads from plugging, these units contain pads with a smaller fiber diameter than the older models. These units are installed for horizontal gas flow through the unit, rather than vertical gas flow, which allows for better drainage (EPA, 1993a).

The applicable EPA control device codes for this category are 014 (Mist Eliminator - High Velocity, I.E. V>250 FT/MIN), 015 (Mist Eliminator - Low Velocity, I.E. V<250 FT/MIN), 134 (Demister), 151 (Fiber Mist Eliminator), and 152 (Mist Eliminator - High Efficiency). Pechan selected code 014 for this device type, although this device type is not limited to high velocity applications.

Application

Mesh-type mist eliminators are used to control mist emissions. They have been demonstrated to be effective for controlling chromic acid mists from hexavalent chromium electroplating tanks (EPA, 1993a).

Control Efficiency

One of the major factors that affect mesh-pad mist eliminator performance is the tendency of the unit to plug. The mesh pad must be flushed frequently with water to prevent pollutant buildup and eventual plugging. Mesh-pad mist eliminators should be washed down at least once a day. Velocity of the gas stream and the particle size of the entrained pollutant are additional factors that affect the performance of the mesh pad assembly. Gas velocities should be maintained high enough to optimize collection through inertial impaction yet not cause reentrainment.

EPA (1993a) provides control efficiency data for mesh-pad mist eliminators used to control chromic acid mist from hexavalent chromium electroplating baths. For tests conducted on three mesh-blade mist eliminators at three separate plants, average control efficiencies ranged from 98.7 to 99.7 percent for chromic acid mist. The vendor of this technology estimates a control device efficiency between 96 and 99 percent. Control efficiency data for PM10 and PM2.5 could not be identified. Based on professional judgment, PM and PM10 control efficiencies were assumed to be 95 to >99 percent. PM2.5 control efficiencies were estimated to range from 90.0 to 99.0 percent. These control efficiency ranges are for stand-alone units that are used as the primary control device.

Monitoring Parameters:

If not used as part of larger control system (e.g. on top of scrubber), **quarterly visual checks for holes or tears.**

Record-Keeping Requirements:

Quarterly visual checks for holes, tears, etc.

Momentum Separator

Description

Momentum separators are part of a group of air pollution controls called mechanical collectors, or precleaners, because they are often used to remove larger, abrasive particles by mechanical means prior to other downstream collection devices. Momentum separators are also referred to as impingement separators, baffle chambers, and knock-out chambers. (EPA, 2003)

Momentum separators are add-on control devices that use both gravity and particle inertia (momentum) to separate particles from the gas stream. Separation occurs by forcing the gas flow to sharply change direction so that the momentum of the particles carries the particles across the gas flow direction and into a collection hopper. The simplest designs provide a 90- to 180-degree turn in the gas flow to separate large particles. In some designs, baffles are added to increase the number of turns in the gas flow direction providing for a modest increase in collection efficiency. Typically, the gas 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 collect in the bottom of the chamber. Momentum separators require less space but have higher pressure drops than expansion chambers and multiple-tray chambers (EPA, 1982).

EPA doesn't provide an applicable control device code for this device. Thus, Pechan assigned a new code 502 to this device.

Application

Momentum separators are used on a wide variety of processes in many different industries. Momentum separators are used to control larger sized PM, primarily PM10 or greater. For most applications, momentum separators have been replaced by cyclones, primarily because cyclones have lower space requirements and higher collection efficiencies (EPA, 2003).

Momentum separators have been operated at temperatures as high as 540°C (1000°F). Inlet gas temperatures are only limited by the materials of construction (EPA, 2003). Cold air leaking into the momentum separator can also cause problems, including local gas quenching and condensation. Condensation can cause corrosion, dust buildup, and plugging of the hopper or dust removal system. The use of thermal insulation can prevent operation below the dew point by reducing radiant heat loss (EPA, 2003).

Control Efficiency

Momentum separator efficiency generally increases with increased particle size and/or density; increased gas stream velocity; and increased number of turns, baffles, or other sharp direction changes to gas flow. EPA (1982) presents a fractional collection efficiency curve for a momentum separator controlling flyash. Fractional collection efficiencies are 5 percent or less for a particle size of 5 μm, 10 to 20 percent for a particle size of 10 μm, and up to 99 percent for particle sizes of 90 μm or greater (EPA, 2003).

Because momentum separators use inertia and gravity as particle removal mechanisms, they can achieve higher control efficiencies and collect smaller particles than gravity collectors.

The control efficiency of a momentum separator increases as the gas velocity through the device increases. However, the pressure drop and operating costs also increase with gas velocity; therefore, the optimum velocity must be selected to balance efficiency and operating costs.

For PM, it is concluded that overall control efficiencies range from 30 to 99 percent depending on the size of the particles controlled. The low-end of the range applies to gas streams with a high concentration of particles with diameters ranging from 10 to 40 μm, and the high-end of the range applies to gas streams with a high concentration of particles with diameters 90 μm. The control efficiencies for momentum separators is low for particle sizes less than 10 μm. PM10 control efficiencies were assumed to be 10 percent, and PM2.5 control efficiencies were assumed to be 5 percent.

Monitoring Parameters:

Gas stream velocity and pressure drop.

Record keeping Requirements:

Daily recording of gas stream velocity and pressure drop to show adherence to vendor specifications.

Multiple Cyclone w/o Fly Ash Reinjection

Description

A multiple cyclone (or multi-tube cyclone) consists of many small diameter cyclone units in parallel. Multiple cyclones are used when high efficiency (which requires small cyclone diameters) and large throughput (i.e., large volumetric gas flow rates) are desired. However, this arrangement results in higher pressure losses relative to single cyclones, thus increasing the energy needed to operate them. The housing of a multiple cyclone contains a large number of tubes that have a common gas inlet and outlet in the chamber. The gas enters the tubes through axial inlet vanes that impart a circular motion on the gas flow. The arrangement and diameter of the tubes affect the overall control efficiency of a multiple cyclone (AWMA, 1992; EPA, 1982).

Dust reentrainment in the cyclone tubes can compromise control efficiency. Control efficiency can be improved by hopper evacuation or slip streaming, in which about 15 percent of the total gas flow is drawn off through the hopper. Hopper evacuation reduces dust reentrainment into the cyclone tubes such that the collection efficiency of the multiple cyclone can be increased by 40 to 50 percent. The dust in the slip stream can be cleaned by a small fabric filter and the cleaned slip stream returned to the cyclone exit. This type of arrangement has been used as a retrofit to improve multiple cyclone control efficiencies (AWMA, 1992). An alternative solution to reducing dust reentrainment is to use a straight-through type cyclone rather than a reverse-flow type cyclone. Multiple tube arrangements of this type have been commonly installed to control particulate emissions from older coal-fired boilers (AWMA, 1992).

The applicable EPA control device code for this device is 076 (Multiple Cyclone w/o Fly Ash Reinjection).

Application

Multiple cyclones are most frequently used on large fossil fuel-fired boilers because they can handle large gas volumes effectively as a precleaner control device (AWMA, 1992). However, they can be used in most situations where it is necessary to achieve relatively high control efficiencies while handling large gas flow volumes.

Control Efficiency

According to STAPPA/ALAPCO (1996), multiple cyclones can achieve PM control efficiencies of 70 to 90 percent. However, cyclone efficiency declines with particle size. While no accurate estimate of control efficiency can be made without precise details of the cyclone design and fly ash properties, control efficiencies can be 90 percent or more for PM10, but will drop to perhaps 70 percent for PM2.5, and 50 percent for PM10. According to another reference, multiple cyclones can achieve control efficiencies of 80 percent for 5 μm particles (Vatavuk, 1990).

Only one uncontrolled and controlled particle size distribution profile was identified in AP-42 (EPA, 1995b) for a multiple cyclone without fly ash reinjection. This profile is for an electric utility bark-fired-boiler. The PM and PM10 control efficiencies are 80 percent, and the PM2.5 control efficiency is about 83 percent for this control device.

AP-42 (EPA, 1995b) contains seven profiles where the type of multiple cyclone (i.e., without or with fly ash reinjection) is not identified. It was assumed that these profiles are for multiple cyclones without fly ash reinjection. Five of the profiles are for coal-fired electric utility boilers, one is for an oil-fired industrial boiler, and one is for a castable refractory rotary calciner used in the mineral products industry. One profile for a pulverized anthracite coal-fired electric utility boiler indicated PM, PM10, and PM2.5 control efficiencies of 80, 52, and 20 percent, respectively. A second profile for a spreader stoker lignite coal-fired electric utility boiler indicated PM, PM10, and PM2.5 control efficiencies of 80, 59, and 25 percent, respectively. A third profile for a traveling grate (overfeed) bituminous coal-fired electric utility stoker indicated PM, PM10, and PM2.5 control efficiencies of 44, 17, and -73 percent, respectively. A fourth profile for a pulverized lignite coal-fired tangential electric utility boiler indicated PM, PM10, and PM2.5 control efficiencies of 80, 62, and 45 percent, respectively. A fifth profile for a pulverized bituminous pulverized coal dry bottom electric utility boiler indicated PM10 and PM2.5 control efficiencies of 75 and 90 percent, respectively. A sixth profile for an industrial residual oil-fired boiler indicated PM, PM10, and PM2.5 control efficiencies of 80, 78, and 93 percent, respectively. A seventh profile for a multiple cyclone for a rotary calciner in the mineral products industry provided a PM efficiency of 50 percent.

The PM2.5 control efficiencies for three profiles are higher than the PM10 and PM control efficiencies and for one other profile is negative, indicating that the multiple cyclone increased PM2.5 emissions. The wide range in PM2.5 control efficiencies may be associated with the possibility that the profiles were developed to represent average emissions based on test results for several multiple cyclones, which would compromise the comparability of uncontrolled and controlled profiles for calculating control efficiencies.

For the low-end of the range of control efficiencies for multiple cyclones without fly ash reinjection, 80 percent control was selected for PM. For PM10, the control efficiencies ranged from about 17 percent to 81 percent. However, five of the seven profiles had efficiencies ranging from 52 to 78 percent. An efficiency of 50 percent was selected to represent the low-end of the range for PM10. For PM2.5, the AP-42 profile data are inconclusive. For existing units, an efficiency of 20 percent was selected to represent the low-end of the range for PM2.5.

The upper-end of the control efficiency range for multiple cyclones for PM control is assumed to be 99 percent. This value is based on the assumption that vendors can optimize the design of multiple cyclones to achieve high PM control efficiencies for some applications. For PM10, 95 percent control efficiency was selected based on the assumption that new installations could be designed and operated to achieve high PM10 control efficiencies. For PM2.5, 70 percent was selected for the upper-end of the control efficiency range based on STAPPA/ALAPCO (1996).

Monitoring Parameters:

Pressure drop was the only parameter identified.

Record-Keeping Requirements:

Record pressure drop every 24 hours of operation.

Non-Selective Catalytic Reduction, Rich Burn Engines

Description

Non-selective catalytic reduction (NSCR) is similar to the catalytic reduction systems used in automobile applications. NSCR does not require the injection of a reducing agent, because it uses unburned hydrocarbons as a reducing agent. The process is called nonselective, because the fuel first depletes all the oxygen present and then removes the NOx. The system is also referred to as a three-way catalyst as it reduces NOx, CO, and hydrocarbons to water, carbon dioxide, and nitrogen (EPA, 1993b). Primarily used to control NOx emissions from rich-burn internal combustion engines, a variant has been successfully used to control NOx generated during the manufacturing of nitric acid (STAPPA/ALAPCO, 1994).

The concentration of oxygen in the exhaust or tail gas should be kept below 0.5 percent to maximize the NOx reduction efficiency. To this end, an oxygen sensor is located in the exhaust, upstream of the catalytic bed. Either via logic controller or manually, the air/fuel mixture is adjusted to maintain a fuel-rich exhaust (EPA, 1993b).

The applicable EPA control device codes for this category are 065 (Catalytic Reduction) and 140 (NSCR (Non-Selective Catalytic reduction)).

Limitations

This control technology is not applicable to lean-burn engines (EPA, 1992a). For optimum efficiency, the catalyst must be maintained at a temperature between 700°F and 1500°F (EPA, 1993b). The sulfur content of the fuel must be limited to less than about 800 parts per million (ppm) by weight to prevent deactivation of the catalyst (CARB, 1997a).

Application

This control is used in rich-burn internal combustion engines and nitric acid manufacturing.

Control Efficiency

The typical control efficiency range for NOx is between 90 and 95 percent for rich-burn engines and between 95 and >99 percent for nitric acid manufacturing (STAPPA/ALAPCO, 1994; EPA, 1993b). A typical NOx control efficiency of 95 percent is assumed. Information from the New Jersey Department of Environmental Protection indicates that control efficiencies of 90 percent for CO and 50 percent for VOC are achievable (NJDEP, 2003).

Monitoring Parameters:

Temperature, oxygen concentration.

Record-Keeping Requirements:

Continuous reading of temperature and oxygen concentration.

Ozonation

Description

Enhanced Carbon Adsorption and Catalytic Oxidation are two types of available systems using this technology. The EPA code 082 (ozonation) was assigned as the MPCA code for this technology.

The enhanced carbon adsorption system combines wet scrubbing, carbon adsorption, and ozone reaction to remove organic vapors from an air stream. The air stream is pre-filtered to remove particulates. The organic-laden air then enters a photolytic reactor where it is exposed to ultraviolet light and mixed with activated oxygen/ozone. The air then enters a countercurrent ozonated water scrubber, where the organic vapors are transferred to the liquid phase. The water is oxidized in a reactor recycle tank. The organics are oxidized to form carbon dioxide, water, and HCl, if chlorine atoms are present. After the reactor, the air stream enters a coalescer to remove any water droplets entrained in the air stream. The air stream then enters one of two activated carbon beds, which remove any remaining organics that did not dissolve in the water. The off-line bed is sealed and fed oxidant to regenerate the carbon.

Because most applications for oxidizing VOCs with ozone use ozonated water to treat VOCs which are either in the liquid phase, or had been absorbed by some liquid. So, at least one gaseous ozonation system has been developed, which uses a catalytic reactor to oxidize VOCs using small amounts of ozone at relatively low temperatures (160 to 220°F). The catalyst is heated by specific-wavelength ultraviolet lamps, then passed over a second catalyst to eliminate any excess ozone, and finally an adsorbent bed made up of bases to capture any residuals or acids. Another system combines an ozone and ultraviolet light gas-phase reactor with a counter-current ozonated water scrubber and a carbon adsorber (RTI, 1995).

Application

The Enhanced Carbon Adsorption system is applicable to paint booths and similar industrial systems where organic solvents are used.

As for Catalytic Oxidation type system, most of the information available is from laboratory or pilot plant studies, as this technology is not yet widely represented in the field (RTI, 1995).

Control Efficiency

The typical control efficiency range for the Enhanced Carbon Adsorption system is 95 to >99 percent (RTI, 1995). This control efficiency range is based on limited industrial application and pilot plant data.

The typical control efficiency range for the Catalytic Oxidation system is from 95 to >99 percent (RTI, 1995). This control efficiency range is based on limited industrial application and pilot plant data. The feed concentration ranges from <2 ppmv to 200 ppmv.

Monitoring Parameters:

For the Enhanced Carbon Adsorption system, **ozone concentration**, exhaust flow rate, and outlet VOC concentration are suggested as monitoring parameters.

For the Catalytic Oxidation system, **ozone concentration** and catalyst temperature are suggested to be monitored.

Record-Keeping Requirements

Continuous recording of ozone concentration, exhaust flow, and outlet VOC concentration to show adherence to vendor specifications and recording of individual VOC species outlet concentrations as per permit requirements are suggested for the Enhanced Carbon Adsorption system.

Continuous recording of ozone concentration and catalyst temperature are suggested for the Catalytic Oxidation system.

Packed-Bed Scrubber (Fiber-Bed, Moving-Bed, Cross-Flow, Grid-Packed)

Description

In vertical-flow packed-bed scrubbers, liquid is introduced above the packing and flows down through the bed. The packing material, such as raschig rings, pall rings, berl saddles, and crushed rock, is held in place by wire mesh retainers and supported by a plate near the bottom of the scrubber. As the liquid flows through the packing, it forms a thin film on the packing material. This film collects the PM in the gas stream as the gas is forced through the packing. Types of packed-bed scrubbers include standard single and double packed-bed scrubbers, fiber- or filter-bed scrubbers, moving-bed scrubbers, cross-flow scrubbers, and grid-packed scrubbers (EPA, 1982; McIlvaine, 1995).

Packed-bed scrubbers used to control chromic acid mist are either horizontal or vertical countercurrent-flow units equipped with one or two packed beds followed by a chevron-blade mist eliminator. Control device vendors estimate that removal efficiencies for these units range from 95 to 99 percent. The scrubber also contains a mist elimination section located downstream of the packed bed(s) to collect any water carry-over. Generally, a conventional chevron-blade mist eliminator is used. The packing media used to control chromic acid mist typically are ballast rings or saddle-shaped packing made of polypropylene (EPA, 1993a).

Fan-separator packed-bed scrubbers are also used to control acid mists. They consist of two stages: a dynamic scrubbing stage followed by an impingement stage. In the first stage, ventilation air is ducted into the eye of a backward-blade centrifugal fan, where it is sprayed with a small volume of water or other scrubbing liquid under high pressure. In the second stage, the exhaust gas flows into an expansion chamber containing one or two packed beds of tubing made of polypropylene. Control efficiencies are estimated to range from 95 to 99 percent (EPA, 1993a).

Packed-bed scrubbers consist of a chamber containing layers of variously-shaped packing material, such as Raschig rings, spiral rings, or Berl saddles, which provide a large surface area for liquid-particle contact. The packing is held in place by wire mesh retainers and supported by a plate near the bottom of the scrubber. Scrubbing liquid is evenly introduced above the packing and flows down through the bed. The liquid coats the packing and establishes a thin film. The pollutant to be absorbed must be soluble in the fluid. In vertical designs (packed towers), the gas stream flows up the chamber (countercurrent to the liquid). Some packed beds are designed horizontally for gas flow across the packing (crosscurrent) (EPA, 1998).

Physical absorption depends on properties of the gas stream and liquid solvent, such as density and viscosity, as well as specific characteristics of the pollutant(s) in the gas and the liquid stream (e.g., diffusivity, equilibrium solubility). These properties are temperature dependent, and lower temperatures generally favor absorption of gases by the solvent. Absorption is also enhanced by greater contacting surface, higher liquid-gas ratios, and higher concentrations in the gas stream (EPA, 2003). Chemical absorption may be limited by the rate of reaction, although the rate-limiting step is typically the physical absorption rate, not the chemical reaction rate (EPA, 2003).

The applicable EPA control device codes for this category are 001 (Wet Scrubber - High Efficiency), 002 (Wet Scrubber - Medium Efficiency), 003 (Wet Scrubber - Low Efficiency), 117 (Packed Scrubber), 118 (Crossflow Packed Bed), 129 (Scrubber), 141 (Wet Scrubber) and 155 (Packed bed Scrubber - High Efficiency). Pechan has combined all the three types – High Efficiency, Medium Efficiency and Low Efficiency scrubbers into one description because the efficiency difference between high, medium and low scrubbers isn't clearly defined by EPA, nor are there any data in the literature that allow for a distinction of scrubbers by control efficiency level or specific design criteria from which control efficiency could be inferred.

Inorganic Gases Control

Water is the most common solvent used to remove inorganic contaminants. Pollutant removal may be enhanced by manipulating the chemistry of the absorbing solution so that it reacts with the pollutant. Caustic solution (sodium hydroxide, NaOH) is the most common scrubbing liquid used for acid-gas control (e.g., HCl, SO_2, or both), though sodium carbonate (Na_2CO_3) and calcium hydroxide (slaked lime, $Ca[OH]_2$) are also used. When the acid gases are absorbed into the scrubbing solution, they react with alkaline compounds to produce neutral salts. The rate of absorption of the acid gases is dependent upon the solubility of the acid gases in the scrubbing liquid (EPA, 2003).

VOC Control

Absorption is a commonly applied operation in chemical processing. It is used as a raw material and/or a product recovery technique in separation and purification of gaseous streams containing high concentrations of organics (e.g., in natural gas purification and coke by-product recovery operations). In absorption, the organics in the gas stream are dissolved in a liquid solvent. The contact between the absorbing liquid and the vent gas is accomplished in counter current spray towers, scrubbers, or packed or plate columns (EPA, 2003).

The use of absorption as the primary control technique for organic vapors is subject to several limiting factors. One factor is the availability of a suitable solvent. The VOC must be soluble in the absorbing liquid and even then, for any given absorbent liquid, only VOC that are soluble can be removed. Some common solvents that may be useful for volatile organics include water, mineral oils, or other nonvolatile petroleum oils. Another factor that affects the suitability of absorption for organic emissions control is the availability of vapor/liquid equilibrium data for the specific organic/solvent system in question. Such data are necessary for the design of absorber systems; however, they are not readily available for uncommon organic compounds.

The solvent chosen to remove the pollutant(s) should have a high solubility for the vapor or gas, low vapor pressure, low viscosity, and should be relatively inexpensive. Water is used to absorb VOC having relatively high water solubilities. Amphiphilic block copolymers added to water can make hydrophobic VOC dissolve in water. Other solvents such as hydrocarbon oils are used for VOC that have low water solubilities, though only in industries where large volumes of these oils are available (e.g. petroleum refineries and petrochemical plants; EPA, 2003).

Another consideration in the application of absorption as a control technique is the treatment or disposal of the material removed from the absorber. In most cases, the scrubbing liquid containing the VOC is regenerated in an operation known as stripping, in which the VOC is desorbed from the absorbent liquid, typically at elevated temperatures and/or under vacuum. The VOC is then recovered as a liquid by a condenser (EPA, 2003).

PM Control

In packed-bed scrubbers, the gas stream is forced to follow a circuitous path through the packing material, on which much of the PM impacts. The liquid on the packing material collects the PM and flows down the chamber towards the drain at the bottom of the tower. A mist eliminator is typically positioned above/after the packing and scrubbing liquid supply. Any scrubbing liquid and wetted PM entrained in the exiting gas stream will be removed by the mist eliminator and returned to drain through the packed bed.

In a packed-bed scrubber, high PM concentrations can clog the bed, hence the limitation of these devices to streams with relatively low dust loadings. Plugging is a serious problem for packed-bed scrubbers because the packing is more difficult to access and clean than other scrubber designs. Mobile-bed scrubbers are available that are packed with low-density plastic spheres that are free to move within the packed bed. These scrubbers are less susceptible to plugging because of the increased movement of the packing material. In general, packed-bed scrubbers are more suitable for gas scrubbing than PM scrubbing because of the high maintenance requirements for control of PM (EPA, 2003).

Inlet temperatures are usually in the range of 4 to 37°C (40 to 70°F) for waste gases in which the PM is to be controlled, and for gas absorption applications, 4 to 38°C (40 to 100°F). In general, the higher the gas temperature, the lower the absorption rate, and vice-versa. Excessively high gas temperatures also can lead to significant solvent or scrubbing liquid loss through evaporation (EPA, 2003).

Application

Packed-bed wet scrubbers have been used in the following industries to control PM emissions: primary and secondary non-ferrous metals processing (e.g., aluminum), coke production, pulp and paper manufacturing, chemical manufacturing, electroplating, and incineration of hazardous, liquid, and gaseous wastes (EPA, 1973b; EPA, 1982; EPA, 1993a; McIlvaine, 1995).

Control Efficiency

The primary operating parameters affecting the performance of packed-bed scrubbers are the liquid-to-gas ratio and the superficial gas velocity entering the packed bed. Other factors that affect the performance of a packed-bed scrubber are the surface contact area of the packing media and the distribution of the packing media in the packed bed. Another factor affecting performance is the excessive pollutant buildup on the packing material that may lead to reentrainment of the pollutant droplets from the packed bed or plugging of the bed.

Published PM, PM10, and PM2.5 control efficiency data for determining low-end control efficiencies for existing packed-bed scrubbers are limited. PM control efficiencies reported in EPA (1973b) are listed as follows by industry (the process type on which the scrubbers were used is shown in parentheses):

- 85 percent - aluminum ore production (electroreduction, prebake cells);
- 94.5 percent - electroplating (general);
- 95.5 percent - phosphoric acid manufacturing (general); and
- 99 percent - hydrochloric acid manufacturing (HCl mist).

EPA (1993a) provides control efficiency data for packed-bed scrubbers used to control chromic acid mist from hard chromium electroplating baths. For test conducted on three packed-bed scrubbers at three separate plants, average control efficiencies ranged from 96.2 to 99.4 percent for chromic acid mist.

Based on the data presented in the two EPA publications, the PM control efficiency range was assumed to be 85 to >99 percent. The low-end PM10 control efficiency value was assumed to be the same as that for PM, and the high-end PM10 control efficiency value was assumed to be 99 percent. For PM2.5, the range is based on the control efficiency range discussed for the "scrubber (general, not classified)" control equipment code.

Monitoring Parameters

Liquid flow rate and flue gas pressure drop.

Record Keeping Requirements

Recording of liquid flow rate and pressure drop every 24 hours.

Packed Column - Gas Absorption

The applicable EPA control device code for this device is 050 (Packed Column – Gas Absorption).

For SOx Control

Description

A packed scrubber consists of an absorption tower filled with packing material designed to provide a large surface area for gas/liquid contact. The absorbent or reagent solution or slurry is fed to the top of the column and travels downward, wetting the packing surfaces; the gas travels upward from the bottom through the packing material. The packed tower design offers a large area for contact of absorbent or reagent and SO_2-laden gas and provides the longest residence time of any scrubber type (EPA, 1981). If used as part of a flue gas desulfurization (FGD) system, the scrubbing solution flow rate must be carefully controlled to avoid flooding (EPA, 2003).

The most common scrubbing liquid used for acid-gas control is sodium hydroxide (NaOH); however, sodium carbonate (Na2CO3) and calcium hydroxide (slaked lime, Ca[OH]2) are also used. Acid gases absorbed into the scrubbing liquid react with the alkaline scrubbing reagents to produce neutral salts. The rate of absorption is dependent on the acid gas solubility in the scrubbing liquid (EPA, 2003).

Application

Packed absorption columns are popular in several types of scrubbing systems. Packed-bed absorbers generally experience a lower pressure and are cheaper to construct than tray-type absorbers (Buonicore, 1992).

Control Efficiency

The typical control efficiency range for SO_2 is from 80 to >99 percent. The control efficiency of the absorber component of a scrubbing system depends upon the overall design of the system and the absorbent used in the system.

For VOC Control

Description

The packed column is the most commonly used device for the control of gaseous pollutants by absorption. Packed columns are usually vertical columns that are filled with packing or devices of large surface area. The liquid is distributed over and trickles down through the packed bed, exposing a large surface area to contact the gas. Flow is usually countercurrent, with liquid flowing down and gas upward. Packed columns are used to remove gas, vapor and odors. Though not as common, concurrent and crossflow configurations are also used.

Packings are ceramic, plastic, and metal, and come in a large variety of shapes and sizes, nominally from 0.25 to 3.5 inches. Selection is based on various performance criteria.

Application

Absorption is used for VOCs and inorganic gases. It is, however, more commonly employed for inorganic vapors (e.g., hydrogen sulfide, NH_3, chlorides, and fluorides) than for organic vapors, because of several limitations and problems. One problem is the availability of a suitable solvent. The vapor must be soluble in the absorbing liquid. Depending on the organic to be absorbed, water, mineral oils, or other nonvolatile petroleum oils may be used.

Water is generally the preferred solvent for inorganic vapor absorption. It is typically used on a once-through basis and then discharged to a waste-water treatment system. The effluent may require pH adjustment to precipitate metals and other HAPs as hydroxides or salts; these are typically less toxic and can be more easily disposed of.

VOC control by gas absorption is generally limited to packed or plate towers and for relatively high VOC concentrations (approximately 1,000 ppmv and higher) of readily water-soluble organics (most alcohols, ethylene oxide, organic acids, aldehydes, ketones, amines, and glycols) (AWMA, 1992). Packed columns are frequently used for handling corrosive materials, liquid with foaming or plugging tendencies, or where excessive pressure drops would result from use of plate columns. Packed columns are usually less expensive than plate towers for the same design application.

In chemical processing, absorption is most commonly applied to recover raw material and/or product in the separation and purification of gaseous streams containing high concentrations of organics (e.g., in natural gas purification and coke by-product operations).

Another consideration is the treatment or disposal of the material removed from the absorber. This must be addressed to effect complete control. In most cases, organics are stripped out (desorbed), either at elevated temperatures and/or under vacuum and then must be recovered as a liquid by a condenser. The stripped vapor may also be destroyed by incineration. In some cases, water containing absorbed VOCs is treated by other direct means, such as ozonation, chemical neutralization, or chemical oxidation.

For uncommon VOCs/HAPs, vapor/liquid equilibrium data for the specific (VOC/HAP)/solvent system may not be readily available. As these data are necessary in designing the absorber system, absorption is not a practical control method in these cases.

Absorption has been used to control VOCs from surface coating operations, waste handling and treatment ring plants, coffee roasters, chromium plating units, petroleum coker units, fish meal systems, smoke generators, and varnish and resin cookers. (EPA, 1992b)

Control Efficiency

The typical control efficiency range for VOCs is from 70 to >99 percent (Grossman, 1997; EPA, 1991a). For inorganic HAP gases, the control efficiency range is from 85 to >99 percent (EPA, 1991a). The packed tower is designed to meet the desired control efficiency for the specified operating conditions. The designer considers many variables, including solubility of the compound (or combination of compounds) in the absorbent, concentration, temperature, gas flow rate, liquid flow rate, packing factor, tower height and cross section.

Monitoring Parameters:

Scrubbing liquid flow rate and flue gas pressure drop (scrubbing liquid pH, if needed).

Record-Keeping Requirements:

Recording of scrubbing liquid flow rate and pressure drop every 24 hours (pH of scrubbing liquid, if needed).

Photocatalytic Oxidation

Description

VOC-laden effluent air from a standard soil vapor extraction air stripping process is delivered to a reactor where VOCs or chlorinated VOCs (CVOCs) are trapped on the surface of a proprietary catalytic adsorbent. In the presence of ultra-violet light, generated by black light ultra-violet bulbs, the trapped contaminants are catalytically destroyed (oxidized) on the adsorbent, continuously regenerating the adsorbent. For CVOCs, HCl and chlorine gas are formed and removed, if necessary, depending on their concentration (Kittrell and Quinlan, 1995).

There is no applicable EPA control device code for this device. Thus, Pechan assigned a new code 514 to this device.

Application

This technology is applicable to low concentrations of VOCs and CVOCs (up to 500 ppmv), such as those found in air stripper effluent from groundwater remediation projects. The principal advantage offered by this technology is that oxidation occurs at ambient temperature, resulting in lower energy costs and lower costs for materials of construction.

First commercial operation is scheduled for spring of 1998 (Kittrell, 1997). Potential future commercial applications include electronics manufacturing industry, solvent degreasing, aircraft industry, and urethane foaming operations.

Control Efficiency

The typical control efficiency range for VOCs is from 95 to >99 percent (Kittrell and Quinlan, 1995). Control efficiency range is based on demonstration test data collected at Dover AFB. The inlet airstream to the photocatalytic destruction unit was 50 to 60 scfm and contained between 900 parts per billion and 3 ppm of dichloroethane. No products of incomplete combustion (such as phosgene) were observed in the exhaust air.

Monitoring Parameters:

Presence of ultra-violet light, inlet and outlet VOC concentrations.

Record-Keeping Requirements:

Continuous recording of presence of ultra-violet light, inlet and outlet VOC concentrations.

Refrigerated Condenser

Description

Refrigerated recovery systems include a refrigeration unit, a heat exchanger/evaporator, storage for the chilled and defrost brines or refrigerants, and a vapor condenser. Such systems are sold as packaged units that contain all the necessary piping, controls, and components.

The applicable EPA control device codes for this category are 073 (Refrigerated Condenser) and 132 (Condenser).

Application

Refrigeration systems are particularly well suited for applications with high value organics, such as the recovery of hydrocarbon vapors from gasoline marketing operations and recovery of dry cleaning solvents. These systems are also best suited to emission streams containing high concentrations of organic emissions. For dilute streams, the control cost per ton of organic compound recovered would very high (EPA, 2001).

Control Efficiency

The typical control efficiency range for this control is 50 to 95 percent. Refrigerated condensers are operated at efficiencies between 50 and 95 percent (EPA, 1992b). For gasoline vapor recovery, refrigeration units have the capacity of recovering more than 90 percent of the organics when the gas entering the condenser consists of 35 percent gasoline vapors by volume. Refrigeration units will recover approximately 70 percent of the organics when the gas entering the condenser consists of 15 percent gasoline vapor by volume (EPA, 1992b). For recovery of dry cleaning solvents, efficiencies of 95 percent and above have been documented (AWMA, 1992). For recovery of organics from vent streams in the petroleum industry, efficiencies range between 85 and 95 percent (AWMA, 1992). Based on these data, a typical control efficiency of 90 percent is assumed for VOC and VOT.

Monitoring Parameters:

Coolant temperature and other manufacturer's specifications

Record-Keeping Requirements:

Continuous recording or hourly recording of coolant temperature and other specifications required by the manufacturers.

Regenerative Catalytic Oxidizer

Description

The regenerative catalytic oxidizer is similar in operation to an RTO, except that it uses a precious metal catalyst in the packed bed, allowing oxidation to occur at lower temperatures (approximately 800°F). The lower oxidation temperature reduces the amount of natural gas needed to fuel the VOC abatement system. The RCO also destroys CO in the VOC-laden airstream. NOx emissions are also lower as the system burns less fuel and operates at lower temperatures than RTOs (Gay, 1997).

There is no applicable EPA control device code for this device. Thus, Pechan assigned a new code 509 to this device.

Application

This control is most effective in facilities that operate fairly continuously and have air flow rates exceeding 10,000 scfm. It is applicable in controlling VOCs from coating operations, automotive manufacturing, and forest and wood products manufacturing. It is not advised for airstreams containing silicon, phosphorous, arsenic, or other heavy metals, which will poison the catalyst. The catalyst's performance will also be affected by masking or fouling by particulates in the gas stream (Gay, 1997).

Control Efficiency

The typical control efficiency range is between 90 and 99 percent. For low pollutant concentrations (< 100 ppmv), control efficiencies are generally 90 to 95 percent. For higher pollutant concentrations (> 100 ppmv), control efficiencies of 95 to 99 percent can be achieved (AWMA, 1992; EPA, 1991a; Chen, 1996).

The relative destructibility of alcohols is high. Other compounds (listed in order of decreasing destructibility) are cellosolves/dioxane, aldehyde, aromatics, ketones, acetates, alkanes, and chlorinated hydrocarbons. However, 98 to 99 percent destruction efficiency can still be achieved with sufficiently low space velocities and/or high inlet temperature.

The average VOC control efficiency at gravure printing presses ranges from 94 to 99.5 percent when a total enclosure capture system with an add-on destruction device (either catalytic, regenerative or thermal incineration, or carbon adsorption) is used (TRC, 1993). Flexographic printing presses controlled by catalytic incineration may achieve 90 to 98 percent overall efficiency (AWMA, 1992). A metal oxide catalyst must be used on flexographic printing presses to avoid poisoning by chlorinated solvents.

Monitoring Parameters:

These include **chamber temperature** and residence time or outlet VOC concentration.

Record-Keeping Requirements:

Continuous recording or hourly recording of chamber temperature and residence time or outlet VOC conc.

Regenerative Thermal Oxidation

Description

Regenerative thermal oxidation (RTO) uses a high-density media such as a ceramic-packed bed still hot from a previous cycle to preheat the incoming VOC-laden stream. The preheated, partially oxidized gases then enter a combustion chamber where they are heated to final oxidation temperature (1400 to 2000°F) and maintained at this temperature to achieve maximum destruction. The purified, hot gases exit this chamber and are directed to one or more different ceramic beds cooled in an earlier cycle. Heat from the process gases is absorbed by these beds before the gases are exhausted to the atmosphere, at temperatures only slightly above inlet conditions.

Advantages of the RTO system are: 1) high operating temperatures provide greater destruction efficiency and better control of air toxics and malodorous gases, 2) RTOs are less susceptible to problems with chlorinated compounds, 3) high heat recovery (85 to 95 percent) results in lower auxiliary fuel costs, 4) generally lower NOx emissions than in thermal oxidation.

Disadvantages of the RTO system are 1) large size and weight, 2) expensive installation, 3) higher capital costs compared to other oxidizers, 4) more moving parts requiring maintenance.

There is no applicable EPA control device code for this device. Thus, Pechan assigned a new code 510 to this device.

Application

The regenerative system is most favorable for design scenarios with high flows (>10,000 scfm) and low solvent concentrations (less than 10 percent of the lower explosive limit). The high heat recovery of the system makes it economically advantageous (Renko, 1994). This type of incinerator is used to control VOC emissions from operations such as metal fabrication, automotive manufacturing, and forest and wood products manufacturing (EPA, 2003).

Control Efficiency

The control efficiency depends upon design criteria, such as chamber temperature, residence time, inlet VOC concentration, compound type, and degree of mixing (EPA, 2003). The typical control efficiency range is from 95 to >99 percent, with lower efficiencies generally being associated with lower concentration flows (EPA, 1995a, RTI, 1995; Power, 1996).

Monitoring Parameters:

These include **chamber temperature** and residence time or outlet VOC concentration.

Record-Keeping Requirements:

Continuous recording or hourly recording of chamber temperature and residence time or outlet VOC conc.

Selective Catalytic Reduction

Description

Selective catalytic reduction (SCR) is the chemical reduction of NOx with a reducing agent (usually NH_3 or urea) over a catalytic bed in the presence of oxygen to produce nitrogen gas and water. SCR is potentially applicable to flue or exhaust gases under oxidizing conditions greater than one percent oxygen (CARB, 1997a).

SCR catalysts are either base metals, zeolites, or precious metals. Base metal catalysts constructed of titanium or vanadium oxides are active at temperatures above 450°F, with an optimum temperature range above 570°F. Temperatures in excess of 800°F or 850°F can lead to thermal breakdown of base metal catalysts. Zeolite catalysts are active at temperatures above 675°F, with an operational temperature range exceeding 1000°F. Precious metal catalysts are constructed of platinum and palladium. These catalysts operate effectively at temperatures between 300°F and 550°F (CARB, 1997a).

The applicable EPA control device codes for these categories are 065 (Catalytic Reduction) and 139 (SCR (Selective Catalytic Reduction).

Limitations

The potential exists of catalyst fouling, erosion or poisoning. Waste gas streams with high levels of particulate may require a sootblower to reduce deposition of the particulate onto the catalyst. Typical catalyst life is approximately five years for coal and slightly longer for oil or gas. Some retrofitting may not be as effective as other due to the available space constraints imposed by furnace design (STAPPA/ALAPCO, 1994). As with SNCR technology, the potential for NH_3 slip and associated problems exist. In some applications, forced air induction may be required to overcome the pressure drop across the catalyst bed (STAPPA/ALAPCO, 1994).

Application

SCR has been applied to annealing furnaces, cement kilns, glass furnaces, internal combustion engines, industrial and commercial boilers, nitric acid process, process heaters, gas turbines and utility boilers. SCR can be cost effective for large industrial boilers and process heaters operating at high to moderate capacity factors (>100 MMBtu/hr or >10 MW for coal-fired; and >50 MMBtu/hr or >5 MW for gas-fired boilers; EPA, 2003).

Control Efficiency

The typical control efficiency range for NOx is between 50 and 95 percent. SCR has the potential of very high control efficiencies (STAPPA/ALAPCO, 1994). SCR can achieve high reduction efficiencies (>70 percent) on NOx concentrations as low as 20 ppm. Higher efficiencies are possible with higher NOx levels; however, above 150 ppm, the reaction rate does not increase significantly (EPA, 2003). Maximum control efficiencies are limited by the amount of acceptable capital and operating costs.

Monitoring Parameters:

Ammonia or urea level, discharge level of NOx, temperature, and other manufacturer's specifications.

Record-Keeping Requirements:

Record each parameter every 24 hours and other specifications required by the manufacturers.

Selective Non-Catalytic Reduction

Description

The majority of selective non-catalytic reduction (SNCR) applications employ one of two commercially available SNCR technologies. These are the Thermal DeNOx® system developed by Exxon and the NOxOUT® process, developed by the Electric Power Research Institute (EPRI).

"Thermal DeNOx," developed and patented by Exxon Research and Engineering Company, is based on the reaction between NOx in flue gas and NH_3, which produces nitrogen and water. In the temperature range of 1650°F to 1850°F, the reaction occurs through the injection of NH_3 without the assistance of a catalyst. The addition of hydrogen along with NH_3, will increase the effective reaction temperature range by dropping the low point to 1300°F (CARB, 1997a).

"NOxOUT" was originally developed for the EPRI and is currently licensed by Fuel Tech. This method injects urea or other similar amine salt compounds into the oxygen-rich upper furnace or high temperature convection section of the boiler to promote NOx reduction. With the addition of other proprietary reagents, NOxOUT has achieved acceptable levels of NOx reductions between 800°F to 2100°F (CARB, 1997a).

For either technology, the temperature of the reaction is the primary variable for effective NOx control (EPA, 1992a).

Urea-based systems have the advantage that urea is a non-toxic liquid that can be stored and handled more safely than ammonia. Also, urea solution droplets can penetrate further into the flue gas when injected and provide better mixing. However, urea is more expensive than ammonia.

Two different records were provided in the database with NOx efficiencies that are specific to different applications (see control efficiencies discussion below). The applicable EPA control device codes for these categories are 032 (Ammonia Injection) and 107 (Selective Non Catalytic Reduction for NOx).

Limitations

Both NH_3 and urea-based SNCR can produce unacceptable NH_3 slippage (STAPPA/ALAPCO, 1994). When combusting high-sulfur fuels, high levels of NH_3 in the boilers can lead to ammonium bisulfate deposition on downstream components. These depositions can lead to equipment failure (EPA, 1994a). When high-chloride coals are burned, NH_3 slip may cause the formation of ammonium chloride which exits the exhaust stacks as a highly visible, white plume. Nitrous oxide can be generated as a reaction byproduct of the SNCR systems at levels as high as 25 percent of the NOx reduction. While not a contributor to ground-level ozone, nitrous oxide is a greenhouse gas (STAPPA/ALAPCO, 1994).

Application

SNCR has been applied to utility boilers, glass furnaces, reciprocating, steel annealing furnaces, cement kilns, process heaters, and industrial and commercial boilers. Sources with furnace exit temperatures between 1550°F and 1950°F, residence times of greater than one second, and high levels of uncontrolled NOx are good candidates for SNCR (EPA, 2003).

Control Efficiency

The control efficiency range for NOx is from 20 to 70 percent (STAPPA/ALAPCO, 1994). The control efficiencies are a function of the fuel type, the amount of NH_3 or urea injected, the reaction temperature, residence time, and application. Separate records were developed for SNCR application to boilers versus process heaters, since application to boilers has shown slightly higher efficiencies. The typical efficiency for boilers is 50 percent, while the typical efficiency for process heaters is 40 percent.

Monitoring Parameters:

Ammonia or urea level, discharge level of NOx, temperature.

Record-Keeping Requirements:

Daily records each parameter and ratio of NOx to ammonia or urea.

Silent Discharge Plasma Technology

Description

Another type of non-thermal plasma is silent discharge plasma technology (SDPT). SDPT is an oxidation and reduction process that uses a pulsed electrical discharge system to create highly reactive free radicals that decompose organic compounds in airstreams. Prototype testing has been conducted at McClellan and Tinker Air Force Bases by the Los Alamos Chemical and Environmental Research and Development Group. Oxidation of VOCs is accomplished with electrical energy.

There is no applicable EPA control device code for this device. Thus, Pechan assigned a new code 515 to this device.

Application

The primary application of this control has been in treating gases from air strippers, soil vapor extraction systems, and incinerators at McClellan Air Force Base, with potential for use in the petroleum, chemical, electronics, water and wastewater treatment industries. With chlorinated VOCs, the reaction products are hydrochloric acid and other compounds, which must then be treated by wet scrubbing.

Control Efficiency

The typical control efficiency range for VOCs is from 95 to 99 percent (Reimers and Gross, 1996). The prototype demonstration system has achieved removal efficiencies greater than 95 percent for chlorinated VOCs such as TCE, trichloroethane, PCE, carbon tetrachloride, benzene, toluene, ethylbenzene, and total xylenes, polychlorinated biphenyl surrogates and chlorofluorocarbons. Removal efficiencies for other VOCs were slightly higher, up to a maximum of 99.4 percent (Pollution Engineering, 1996; Reimers and Gross, 1996).

Monitoring Parameters:

Electrical values: voltage, current.

Record Keeping Requirements

Continuous recording of electrical values voltage, current.

Spray Chamber Wet Scrubber (Spray Tower, Mist Scrubber, Cyclonic Spray Tower, Vane-type Cyclonic Tower)

For PM Control

Description

In spray chambers, particulate-laden gas is introduced into an empty cylindrical or rectangular chamber where it comes into contact with liquid droplets generated by spray nozzles. Particles collide with the droplets, are collected into the liquor, and carried out of the scrubber. Types of spray chambers include spray towers, cyclonic spray towers, and vane-type cyclonic towers (EPA, 1982). In the spray tower, gas flows upward though a bank or several successive banks of spray nozzles. The spray tower has a very low gas pressure drop, and practically all of the contacting power is derived from the liquid pressure and flow rate (EPA, 2003).

The applicable EPA control device codes for this category are 052 (Spray Tower), 123 (Spray Scrubber), and 153 (Water Sprays).

Application

Spray chamber wet scrubbers have been used in the following industries to control PM emissions: primary and secondary non-ferrous metals processing (e.g., copper, lead, and aluminum), steel production, pulp and paper manufacturing, asphaltic concrete manufacturing, and surface coating (EPA, 1973b; EPA, 1982).

Control Efficiency

Published PM, PM10, and PM2.5 control efficiency data for determining low-end control efficiencies for existing spray chambers are limited. PM control efficiencies reported in EPA (1973b) are listed as follows by industry (the process type on which the scrubbers were used is shown in parentheses):

- 70 percent - steel production (basic oxygen furnace);
- 70 percent - aluminum ore production (bauxite crushing and handling);
- 71 percent - aluminum ore production (horizontal stud Soderberg process);
- 75 percent - aluminum ore production (vertical stud Soderberg process);
- 80 to 83 percent - aluminum ore production (electroreduction, prebake cells);
- 90 percent - surface coating (varnish and shellac); and
- 99.9 percent - asphaltic concrete manufacturing (rotary dryer).

Based on these data, 70 and >99.5 percent were selected to represent the PM control efficiency range for spray chamber wet scrubbers. No control efficiency data could be identified for PM10 and PM2.5. The low-end PM10 control efficiency value was assumed to be the same as that for PM, and the high-end PM10 control efficiency value was assumed to be 99 percent. For PM2.5, the range is based on the control efficiency range discussed for the "scrubber (general, not classified)" control equipment code.

For SOx Control

Description

A spray tower scrubber can be vertical or horizontal. The absorbing or reactive material slurry or solution is introduced in the scrubber in atomized droplets through the spray nozzles at the top. The flow of gas and absorbing slurry or solution is crosscurrent in a horizontal design and countercurrent in a vertical design. Absorbate of varying degrees of richness can be introduced at different stages in the tower. Often the fresh absorbate (recycle and makeup streams) is introduced at the rear or top of the absorber (the last stage) where the SO_2 content of the gas stream is lowest. The absorbate collected in the last stage is pumped forward to the next stage. In effect, the absorbate "flows" countercurrent to the gas flow. The first stage of the absorber has the highest SO_2 concentration gas stream and an absorbing slurry or solution that has had much of its active absorbent or reactive ability exhausted (EPA, 1981).

Application

Spray towers have been used in many different scrubbing systems and became popular due to their simplicity (Smith, 1994; Soud, 1993; Satriana, 1981). They have been used as part of FGD systems to control emissions from electric utilities and industrial sources firing coal and oil. Wet scrubbers have also been applied to SO_2 emissions from primary nonferrous metals processing. However, sulfuric acid or elemental sulfur plants are more common controls for these sources, because of the high SO_2 concentrations associated with these processes (EPA, 2003).

Control Efficiency

The typical control efficiency range is from 80 to >99 percent. The control efficiency of the absorber component of a scrubbing system depends upon the overall design of the system and the absorbent used in the system. Most current applications have a control efficiency of greater than 90 percent (EPA, 2003).

For VOC Control

Description

The spray tower is another wet scrubbing device for the control of gaseous pollutants by absorption. Spray towers are vertical enclosed columns with nozzles that atomize an absorbent liquid suitable for the waste gas stream. Flow is usually countercurrent, with liquid flowing down and gas upward. Spray towers are an inexpensive option used to remove gas, vapor, and odors in cases involving highly soluble VOCs or where a low control efficiency is acceptable. Although not as common, concurrent and crossflow configurations are also used.

Mist scrubbers are essentially once-through (non-regenerable) co-current spray towers, in which the absorbing liquid is finely atomized. Both the absorbing mist and the waste gas stream enter the column at the top. The absorbing liquid is generally softened water and hypochlorite, to which other chemicals can be added to enhance absorption in specific cases. The atomizing nozzle creates droplets of absorbing liquid as small as ten micrometers, which provide a large surface area for maximum absorption. The tower is sized to provide the necessary residence time to achieve the desired control efficiency (RTI, 1995).

Application

Spray towers have been applied to light-oil and benzene storage tanks using wash oil as a solvent and have been installed to control odors from wastewater treatment and rendering plants. While spray towers do not suffer from clogging by accumulated residues as packed bed scrubbers, they have the least effective mass transfer capability of the wet scrubber designs and are generally limited to use for particulate removal and with high-solubility gases (EPA, 1992b).

Control Efficiency

The typical control efficiency range is 50 to 95 percent. Lower control efficiencies represent flows containing insoluble compounds at low concentrations, while the higher efficiencies are for flows which contain readily soluble compounds at high concentrations. Traditional spray towers generally are in the lower part of the range, while mist scrubbers can achieve high control efficiencies for highly soluble contaminants (RTI, 1995; Perry and Green, 1984). This device is expected to have a similar GIT control efficiency as other types of wet scrubbers (e.g. Tray-Type Gas Absorption Column), so Pechan applied the same control efficiencies. Thus, for inorganic HAP gases, the range is from 85 to >99 percent (EPA, 1991a).

Monitoring Parameters:

Depending on the application, can be one or more of the following: **liquid flow rate, flue gas pressure drop** and temperature, concentration of reacting solution or slurry if used, pH of absorbing solution.

Record-Keeping Requirements:

Depending on the application and vendor specifications, one or more of the following: daily records of liquid flow rate, flue gas pressure drop and temperature, reacting solution or slurry (if used), pH, and reagent usage.

Supplement for Thermal Oxidation Controls: PM Control by Incinerators

Description

Incinerators/oxidizers vaporize and oxidize particles as part of the combustion process, and are the only PM control devices that do not concentrate the PM for subsequent disposal. PM control is usually the secondary "goal" of the incinerator — VOC control is the primary purpose. The type of PM that is usually controlled by an incinerator is generally soot (particles formed as a result of incomplete combustion of hydrocarbons), coke, or carbon residue. The basic types of incinerators used as control devices for PM removal are thermal incinerators and catalytic incinerators, but flares also provide similar control. However, the use of a catalytic incinerator for PM control is limited because it is prone to severe operating problems with particulate-laden gas streams (EPA, 1982).

The combustion (residence) time required for PM control in an incinerator is dependent on particle size and composition, oxygen content of the furnace, atmosphere, furnace temperature, gas velocity, and extent of mixing of the combustibles. For PM less than 100 μm in diameter, the combustion rate is controlled by chemical kinetics; for PM greater than 100 μm, the combustion rate is controlled by diffusion. Although residence time and incinerator temperature are the primary parameters affecting incinerator performance, other important parameters are the heat content and water content of the gas stream and the amount of excess combustion air (i.e., amount above the stoichiometric amount needed for combustion) (EPA, 1982; EPA, 1992c). Both thermal and catalytic incinerators are usually equipped with heat exchangers to recover a portion of the heat energy generated by the combustion process.

Applicability

Residence time and incinerator temperature required for PM control is much higher than for non-PM sources, based on operating condition requirements for various industrial applications reported by Perry and Green (1984). A review of data included in EPA's 1990 National Inventory showed that the primary source categories where incinerators were used for PM control were petroleum and coal production, chemical and allied product manufacturing, primary metal production, and electronic and other electric equipment manufacturing (EPA, 1996b).

Control Efficiency

Theoretically, all organic material, including VOC, are combustible with combustion efficiency limited only by cost. With sufficient temperature, mixing and residence time, complete combustion should result in greater than 99 percent control of particles containing hydrocarbons (EPA, 1982; EPA, 1992c).

The types of sources, control efficiencies, and types of incinerators, for facilities using incineration for PM control as reported in the 1990 National Inventory are presented below. Based on these data, the general PM and PM10 control efficiency range, encompassing all types of PM, is between 25 and >99 percent. For control of POT, the control efficiency range is assumed to be the same as the VOC control efficiency for all VOC controls using combustion as the primary control method. For control of PIT, the control efficiency range is assumed to be the same as the PM10 control efficiency for all VOC controls using combustion as the primary control method. Industry applications and PM10 control efficiencies are as follows (EPA, 1996b):

Industry/Types of Sources	PM10 Control Efficiency (%)	Types of Incinerators
Petroleum and Coal Products asphalt roofing processes (blowing, felt saturation); mineral calcining; petroleum refinery processes (asphalt blowing, catalytic cracking, coke calcining, sludge converter); sulfur manufacturing	25 - 99.9	Thermal Thermal with Heat Exchanger Catalytic
Chemical and Allied Products carbon black mfg; charcoal mfg; liquid waste disposal; miscellaneous chemical mfg processes; pesticide mfg; phthalic anhydride mfg (xylene oxidation); plastics/synthetic organic fiber mfg; solid waste incineration (industrial)	50 - 99.9	Thermal Thermal with Heat Exchanger Catalytic Catalytic with Heat Exchanger
Primary Metals Industries by-product coke processes (coal unloading, oven charging and pushing, quenching); gray iron cupola and other miscellaneous processes; secondary aluminum processes (burning/drying, smelting furnace); secondary copper processes (scrap drying, scrap cupola, and miscellaneous processes); steel foundry miscellaneous processes; surface coating oven	70 - 99.9	Thermal Thermal with Heat Exchanger Catalytic Thermal and Catalytic
Electronic and Other Electric Equipment chemical mfg miscellaneous processes; electrical equipment bake furnace; fixed roof tank; mineral production miscellaneous processes; secondary aluminum roll/draw extruding; solid waste incineration (industrial)	70 - 99.9	Thermal Thermal with Heat Exchanger Catalytic
Electric, Gas, and Sanitary Services internal combustion engines; solid waste incineration (industrial, commercial/ institutional)	90 – 98	Thermal Thermal with Heat Exchanger Catalytic
Stone, Clay, and Glass Products barium processing kiln; coal cleaning thermal dryer; fabricated plastics machinery; wool fiberglass mfg	50 – 95	Thermal Catalytic
Food and Kindred Products charcoal processing, miscellaneous; corn processing; miscellaneous; fugitive processing, miscellaneous; soybean processing, miscellaneous	70 – 98	Thermal Thermal with Heat Exchanger
Mining asphalt concrete rotary dryer; organic chemical air oxidation units, sulfur production	70 - 99.6	Thermal Catalytic with Heat Exchanger

Industry/Types of Sources	PM10 Control Efficiency (%)	Types of Incinerators
National Security and International Affairs solid waste incineration (commercial/ institutional and municipal)	70	Thermal Thermal with Heat Exchanger
Textile Mill Products plastics/synthetic organic fiber (miscellaneous processes)	88 – 95	Thermal Catalytic
Educational Services solid waste incineration (commercial/ institutional)	80	Catalytic with Heat Exchanger
Industrial Machinery and Equipment secondary aluminum processes (burning/ drying, smelt furnace)	80 – 98	Thermal
Lumber and Wood Products solid waste incineration (industrial)	70	Thermal
Paper and Allied Products Boiler	95	Catalytic with Heat Exchanger
Printing and Publishing surface coating dryer; fugitives	95	Catalytic
Transportation Equipment solid waste incineration (industrial)	70 – 95	Thermal

Thermal Reduction, Adipic Acid

Description

Thermal reduction mixes a NOx tail gas stream with an excess amount of fuel, which is then heated to the mixtures ignition temperature. The combusted gas is passed through a series of chambers to provide adequate residence time to ensure complete combustion. The heat generated during this process is typically recovered (STAPPA/ALAPCO, 1994).

The effectiveness of NOx reduction relies on two factors: temperature and excess fuel. The rate of the combustion/NOx reduction reactions depends on the temperature, with higher temperature leading to faster reaction rates. Higher reaction rates reduce the required residence time, thus decreasing the required size of the unit. However, the cost of fuel limits the feasible operating temperature (EPA, 1991b).

There is no applicable EPA control device code for this device. Thus, Pechan assigned a new code 516 to this device.

Limitations

NOx lost during the manufacturing process is not recovered. There is an additional cost of the reduction fuel. However the heat generated by the thermal reduction can be recovered (STAPPA/ALAPCO, 1994).

Application

This control is used in adipic acid production.

Control Efficiency

The typical control efficiency range for NOx is from 70 to 95 percent (STAPPA/ALAPCO, 1994; EPA, 1992a).

Monitoring Parameters:

Temperature, fuel to NOx ratio, and other manufacturer's specifications

Record-Keeping Requirements:

Continuous reading of temperature, fuel to NOx ratio, and other parameters specified by the vendor.

Tray-Type Gas Absorption Column

The applicable EPA control device code for this device is 051 (Tray-Type Gas Absorption Column).

For SOx Control

Description

A tray absorber promotes gas-slurry contact in a vertical column with transversely mounted perforated trays. The SO_2-laden gas enters at the bottom of the column and travels upward through the perforations in the trays; the reagent slurry is fed at the top and flows toward the bottom. Absorption of SO_2 is accomplished by countercurrent contact between the gas and reagent slurry. A variation of this absorber type is the mobile-bed absorption column, which adds mobile elements to the trays to produce highly turbulent zones for gas/liquid mixing. The sorbent is usually an alkaline slurry, such as limestone, slaked lime, or a mixture of slaked lime and alkaline sly ash. The SO_2 reacts with the sorbent to form a wet mixture of calcium sulfite and sulfate (EPA, 1981).

Application

Tray-type absorber columns are used in wet scrubbing systems, but are not as popular as either spray towers or packed-bed absorber columns. Tray-type absorbers are more resistant to plugging than packed-bed absorbers (Buonicore, 1992)

Control Efficiency

The typical control efficiency range for SO_2 is between 80 and >99 percent. The control efficiency of the absorber component of a scrubbing system depends upon the overall design of the system and the absorbent used in the system.

For VOC Control

Description

Plate or tray-type towers provide contact between the waste gas and liquid absorbent via a series of horizontal plates arranged in a step-like manner. Typically, the plates are designed to retain a layer of liquid on top of each plate as the liquid spills down through the tower from plate to plate. The gas is forced to bubble up through the liquid to achieve intimate mixing at each plate. The bubbling is induced by holes in the plates through which gases rise to the top of the tower. The number of required plates is determined by the difficulty of the mass transfer operation and the desired degree of absorption (EPA, 1992b).

Application

Absorption is used for VOCs and inorganic gases. It is, however, more commonly employed for inorganic vapors (e.g., hydrogen sulfide, chlorides, and fluorides) than for organic vapors, because of several limitations and problems. One problem is the availability of a suitable solvent. The vapor must be soluble in the absorbing liquid. Depending on the organic to be absorbed, water, mineral oils, or other nonvolatile petroleum oils may be used.

Water is typically the preferred solvent for inorganic vapor absorption. It is typically used on a once-through basis and then discharged to a waste-water treatment system. The effluent may require pH adjustment to precipitate metals and other HAPs as hydroxides or salts; these are typically less toxic and can be more easily disposed.

VOC control by gas absorption is generally limited to packed or plate towers. Plate columns are preferred for large-scale operations where internal cooling is desired or where low liquid flow rates would inadequately wet the packing of a packed bed tower. However, plate towers tend to be more expensive than packed towers for the same design objective.

Control Efficiency

The typical control efficiency range is from 70 to >99 percent for VOCs (Grossman, 1997; EPA, 1991a). For inorganic HAP gases, the range is from 85 to >99 percent (EPA, 1991a).

Monitoring Parameters:

Could monitor one or more of the following: **scrubbing liquid flow rate, pressure drop,** pH of scrubbing liquid (if needed), water blowdown.

Record-keeping Requirements:

Daily records of one or more of the following: scrubbing liquid flow rate, pH of scrubbing liquid (if needed), pressure drop, water blowdown.

Tray-Type Scrubber [Impingement Plate, Perforated Plate, Horizontal Impingement-Plate (Baffle)]

Description

A tray-type scrubber typically consists of a vertical chamber with one or more perforated plates mounted horizontally inside a hollow shell. The liquid flows from top to bottom, and the gas flows from bottom to top. Gases mix with the liquid passing through the openings in the plates. After the bottom plate, the liquid and collected PM flow out of the bottom of the chamber. Types of tray-type scrubbers include sieve-type towers, perforated plate scrubbers, impingement-plate scrubbers, and horizontal impingement-plate (baffle) scrubbers. Scrubbers equipped with perforated plates are typically called "sieve tray towers," and scrubbers equipped with rigid baffles placed opposite each perforation are typically called "impingement plate" scrubbers (AWMA, 1992). Particles greater than 1 µm in diameter can be collected effectively by impingement plate scrubbers, but many particles less than 1 µm will penetrate these devices (EPA, 1982).

The applicable EPA control device codes for this category are 055 (Impingement Plate Scrubber) and 115 (Impingement Type Wet Scrubber).

Application

Tray-type wet scrubbers have been used in the following industries to control PM emissions: food and agriculture, chemical manufacturing, pulp manufacturing, gray iron foundry production, lime manufacturing, and coal cleaning (EPA, 1973b; EPA, 1982).

Control Efficiency

Published PM, PM10, and PM2.5 control efficiency data for determining low-end control efficiencies for existing tray-type scrubbers are limited. PM control efficiencies reported in EPA (1973b) are listed as follows by industry (the process type on which the scrubbers were used is shown in parentheses):

- 55 to 85 percent - pulp manufacturing (sulfate pulping recovery boilers);
- 81 percent - diammonium phosphate fertilizer manufacturing (granulator);
- 91 percent - gray iron foundry production (cupola furnace);
- 95 percent - lime manufacturing (crushing operations and rotary and vertical kilns); and
- 99 percent - coal cleaning (thermal, flash, and fluid-bed dryers).

Based on these data, 55 and 99 percent were selected to represent the PM control efficiency range for tray-type wet scrubbers. No control efficiency data could be identified for PM10 and PM2.5. The PM10 control efficiency range was assumed to be the same as the range for PM. For PM2.5, the range is based on the control efficiency range discussed for the "scrubber (general, not classified)" control equipment code.

Monitoring Parameters:

Depending on the application, can be one or more of the following: **liquid flow rate, flue gas pressure drop** and temperature, concentration of reacting solution or slurry (if used), pH of absorbing solution.

Record Keeping Requirements:

Depending on the application and vendor specifications, one or more of the following: daily records of liquid flow rate, flue gas pressure drop and temperature, reacting solution or slurry (if used), pH, reagent usage.

Tube and Shell Condenser

Description

A tube-and-shell condenser is a subcategory of the larger device category of surface condensers. The design of a surface condenser does not permit contact between the coolant and either the vapors or the condensate. Tube and shell condensers constitute the majority of surface condensers. The coolant usually flows through the tubes and the VOC-laden vapor condenses on the outside tube surface. The condensate forms a film on the cool tube which gravity drains from the exchanger. Air-cooled condensers may also be used. These are constructed with tubes with external surface fins through which air is blown. The vapor condenses inside the tubes.

The applicable EPA control device codes for this category are 072 (Tube and Shell Condenser) and 132 (Condenser).

Application

Surface condensers (as opposed to direct contact condensers) constitute the majority of the condensers used for air pollution control. Surface condensers are usually used in conjunction with other equipment to recover or destroy organic emissions. Surface condensers may be located upstream of absorbers, carbon beds, or incinerators to reduce the VOC load entering the more expensive control devices. They have been used successfully in petroleum refining, petrochemical manufacturing, asphalt manufacturing, coal tar dipping operations, degreasing operations, dry cleaning units, and sometimes the surface coating industry (EPA, 1992b).

Control Efficiency

The typical control efficiency range for this control is 50 to 90 percent. Surface condensers are typically operated at efficiencies between 50 and 90 percent (EPA, 1991a). However, where solvent contamination is low and organic vapor concentration is relatively high, recovery efficiencies are reported greater than 96 percent (EPA, 1992b). In cases where ambient air is mixed with the vapor and some contamination is present, efficiencies of about 90 percent are reported (EPA, 1992b). Based on these data, a typical control efficiency of 90 percent is assumed for VOC and VOT.

Monitoring Parameters:

Coolant temperature and flow rate.

Record-Keeping Requirements:

Continuous recording or hourly recording of coolant temperature and other specifications required by the manufacturers.

Vapor Recovery System Stage I – Bulk Plants and Terminals

Description

Stage I vapor recovery systems at bulk plants and terminals collect and process displacement vapors resulting from the loading of gasoline products onto trucks. As gasoline is pumped from the storage tank into a tank truck, the air/vapor mixture is displaced through a vapor collection header system of hoses and pipes to a vapor processor. There are two types of Stage I equipment, dual point and coaxial. Dual point configurations consist of two separate tank openings, one for the delivery of product, and the other for release of vapors. The coaxial configuration has only one tank opening with a tube within a tube. Fuel flows through the inner tube, while vapor is displaced through the annular space between the inner and outer tubes. Typically, the vapors are either recovered as product or destroyed. Multistage refrigeration units and double-bed self regenerating carbon adsorbers are the most common recovery devices used. Ground flares or thermal oxidizers are the most common types of destruction units used.

The applicable EPA control device code for this device is 047 (Vapor Recovery Sys (Incl. Condensers, Hooding, Other Enclosures).

Application

This control is used at bulk gasoline plants and terminals.

Control Efficiency

The typical control efficiency range for this control is 95 to 99 percent (AWMA, 1992, CARB, 1997b). The control efficiency range of 95 to 99 percent represents an overall efficiency range and accounts for the capture efficiency of the collection system and fugitive emission losses due to transfer of product. Therefore, only one record assigned to non-total enclosure (NTE) is provided in the control equipment database.

Monitoring Parameters:

VOC leakage.

Record-Keeping Requirements

Results of monthly or quarterly leakage detection and any necessary repairs.

Venturi or Orifice Scrubber

For PM Control

Description

Venturi scrubbers, also known as venturi jet scrubbers, gas-atomizing spray scrubbers, and ejector-venturi scrubbers, are primarily used to control particulate matter (PM), including PM10 and PM2.5. These devices are also capable of removing high solubility gases and can provide some incidental control of volatile organic compounds (VOC) (EPA, 2003). Venturi and orifice scrubbers are perhaps the most common PM removal devices, in part because they provide higher control of small particles than most other types of scrubbers (EPA, 1982).

In a venturi scrubber (also called a gas atomizing spray scrubber), the static pressure of the incoming gases is converted to velocity pressure (i.e., kinetic energy) as the gases move through the narrow (usually less than 15 cm wide) throat. The required dispersion of target droplets is created by accelerating the gas stream to a high velocity and then using this kinetic energy to shear the scrubbing liquid into fine droplets. The motive force comes primarily from gas-stream kinetic energy, usually injected into the system by a fan. The energy imparted to the gas stream acts on the high-velocity center of the throat. Scrubbing liquid can be injected into the venturi scrubber at the throat zone, at the gas inlet, or against the gas flow in the throat. Venturi scrubbers are typically considered high-energy PM control devices (AWMA, 1992).

As the gas-liquid mixture leaves the throat section, droplets decelerate and further impacts cause agglomeration. An entrainment section, usually a cyclonic separator and/or a mist eliminator after the venturi, separates the liquid droplets and entrained pollutants from the gas stream (EPA, 2003).

Most current designs for venturi scrubbers use the vertical downflow of gas through the venturi throat. These designs incorporate a "wet-approach" or "flooded-wall" entry section to avoid a dust buildup at the wet-dry junction. An adjustable throat provides for adjustment of the gas velocity, and a "flooded" elbow between the venturi and the entrainment separator to reduce wear by abrasive particles (EPA, 2003).

In an orifice scrubber, the gas stream passes over a pool of scrubbing liquid at high velocity just before entering an orifice. The high velocity of the gas entrains a spray of scrubbing liquid droplets, which interact with the PM in and immediately after the orifice (EPA, 1982).

The applicable EPA control device code for this device is 053 (Venturi Scrubber).

Application

Venturi scrubbers have been applied to control PM emissions from utility, industrial, commercial, and institutional boilers fired with coal, oil, wood, and liquid waste. They have also been used in the chemical, mineral products, wood, pulp and paper, and asphalt manufacturing industries; lead, aluminum, iron and steel, gray iron production industries; and municipal solid waste incinerators. Venturi scrubbers typically are applied where it is necessary to obtain high collection efficiencies for fine PM.

In situations where waste gas contains both particulates and gases to be controlled, venturi scrubbers are sometimes used as a pretreatment device, removing PM to prevent clogging of a downstream device, such as a packed bed scrubber, which is designed to collect primarily gaseous pollutants (EPA, 2003).

Control Efficiency

Venturi scrubber collection efficiencies range from 70 to greater than 99 percent, depending upon the application. Collection efficiencies are generally higher for PM with aerodynamic diameters of approximately 0.5 to 5 µm. Some venturi scrubbers are designed with an adjustable throat to control the velocity of the gas stream and the pressure drop. Increasing the venturi scrubber efficiency requires increasing the pressure drop which, in turn, increases energy consumption (EPA, 2003).

Three particle size distribution profiles were identified in AP-42 (EPA, 1995b) for venturi scrubbers. The highest PM, PM10, and PM2.5 control efficiencies calculated from these profiles were slightly lower than those calculated for other profiles for which the type of scrubber was not identified [see discussion of typical control efficiency range for wet scrubbers (general, not classified)]. The lowest control efficiencies calculated from the three profiles for venturi scrubbers were 92.2 percent for PM, 68 percent for PM10, and 25 percent for PM2.5. These values were selected for the low-end of the control efficiency range for venturi and orifice scrubbers, except that the PM and PM10 control efficiency values were rounded to 90 and 70 percent, respectively. The high-end of the control efficiency range for venturi and orifice scrubbers is based on engineering judgment. The high-end of the range for PM and PM10 was assumed to be >99.0 percent, because the pressure drop of a venturi scrubber can be increased to the level needed to achieve control efficiencies of more than 99.0 percent. For PM2.5, it was assumed that new venturi scrubbers can be designed and operated to achieve 99.0 percent control.

For SOx Control

Description

In a venturi scrubber, the SO_2-laden gas is introduced at the top, then passed through the converging section of the scrubber (the venturi throat), and then exited from the scrubber through a diverging section. The venturi shape imparts a high velocity to the gases in the throat, which leads to turbulent mixing of the gases with the absorbent or reactant, which promotes more complete absorption and/or reactions. Absorbent or reactant solutions or slurries are introduced to the gas flow in a variety of ways. Some inject into the throat, others at the gas inlet, and still others, upward against the gas flow in the throat (Buonicore, 1992; EPA, 1981).

Application

Venturi scrubbers are often used before a tower-type absorber in order to remove particulates from the flow as well and sometimes to cool and humidify the gas. They are also used to introduce a scrubbing liquor or slurry to a gas flow in nonregenerable systems, where any particulate in the waste gas is collected with the reacted solution or slurry.

Control Efficiency

The typical control efficiency range is from 80 to >99 percent. The control efficiency of the absorber component of a scrubbing system depends upon the overall design of the system and the absorbent used in the system.

For VOC Control

Description

[See Description for PM Control.]

Application

Venturi scrubbers have a relatively low effective mass transfer capability and are generally limited to use for particulate removal and with high-solubility gases (EPA, 1992b). In situations where waste gas contains both particulates and gaseous pollutants, venturi scrubbers are sometimes used as a pretreatment device, to remove PM that could clog a downstream device, such as a packed bed scrubber (EPA, 2003).

Control Efficiency

The typical control efficiency range is from 50 to 70 percent (Grossman, 1997) (VOC). VOCs are not usually the pollutant intended for control by a venturi scrubber. Any control of VOC emissions would be coincidental to the intended control of particulate matter, for which venturi scrubbers are better suited.

Monitoring Parameters:

Liquid flow rate, flue gas pressure drop and temperature.

Record keeping requirements:

Daily recording of liquid flow rate, flue gas pressure drop and temperature to show adherence to vendor specifications.

Water Blanket

Description

Water may be used as a blanketing medium for some volatile organic liquids that have low solubility in water and relatively high density, such as methylene chloride.

There is no applicable EPA control device code for this device. Thus, Pechan assigned a new code 507 to this device.

Application

Water blanketing has been used in the metal finishing industry to minimize VOC emissions from organic solvents used in paint stripping. The organic liquid must be heavier than and insoluble in water.

Control Efficiency

The typical control efficiency range for VOCs is from 90 to >99 percent.

Monitoring Parameters:

Water level.

Record Keeping Requirements

Daily readings of water level.

Water Curtain

Description

Water curtains (or water sprays) are typically used to remove paint particles from the air in paint spray booths. Emissions of paint particles result from the use of air atomization spray guns (EPA, 1973a). Paint that is not deposited on the substrate being painted is called overspray. The amount of overspray depends on the shape of the substrate, the type of spray gun used, the solids content of the paint, and the experience of the spray gun operator. Overspray is lowest for flat surfaces and higher for irregular surfaces. Electrostatic spraying also decreases overspray.

A ventilation system is used to draw air through a water curtain or sprays located at the back of the booth. A water circulation rate of 10 to 38 gallons per 1,000 cubic feet of exhaust air is recommended. Surface active agents may be added to the water to aid in the removal of paint from the circulating tank (EPA, 1973a).

The applicable EPA control device code for this device is 086 (Water Curtain).

Application

Water curtains (or water sprays) are used in paint spray booths to control PM emissions.

Control Efficiency

According to EPA (1973a), well designed water curtain or spray systems can control paint particles as high as 95 percent. No information was identified on typical low-end control levels for mat or panel filters. Therefore, the low-end of the control effectiveness range was assumed to be 10 percent based on the value used in the previous version of the CEC database. In addition, no information was identified on the control effectiveness of mat or panel filters for PM10 and PM2.5.

Monitoring Parameters:

These could include one or more of the following: **water flow rate**, flue gas pressure drop and temperature.

Record Keeping Requirements:

Daily recording of water flow rate, flue gas pressure drop and temperature.

Wet Electrostatic Precipitator

Description

Wet ESPs are control devices that are designed to remove PM from the flue gas stream using electrical fields and water. They can collect dry materials, fumes, or mist. The basic design of a wet ESP is the same as that for a dry ESP, except that water spray is used to remove the PM captured on the electrode. A typical wet ESP configuration has vertical cylindrical collecting electrodes, with discharge electrodes located in the centers of the cylinders (STAPPA/ALAPCO, 1996). The water flow may be applied intermittently or continuously to wash the collected PM into a sump for disposal (AWMA, 1992).

The applicable EPA control device code for this device is 146.

Application

Wet ESPs can collect sticky particles and mists, as well as highly resistive or explosive dusts. In addition, wet ESPs have no problems with rapping re-entrainment and with back corona. Wet ESPs are useful in obtaining low opacities through the removal of acid gases and mists in addition to fine PM and can provide incidental control of volatile organic compounds. The disadvantage of these devices is the increased complexity of the wash and the additional handling activities (and costs) associated with the collected slurry versus the dry product from a dry ESP. These devices are generally not limited by dust characteristics but are limited by gas temperatures. Typically, the operating temperatures of wet ESPs cannot exceed 170°F (AWMA, 1992; STAPPA/ALAPCO, 1996).

Wet ESPs are usually applied in small applications such as welding, heat treating, plasma cutting, and gear quenching and other processes that produce oil mist, smoke, and fumes (Schrieber, 2005).

Control Efficiency

Only one particle size distribution profile was identified in AP-42 (EPA, 1995b). The profile provided control efficiencies for PM10 and PM2.5 but not PM. The PM10 and PM2.5 control efficiencies are 94.01 and 89.29 percent, respectively. According to AWMA (1992), wet ESPs can achieve PM control efficiencies ranging from 99.0 to 99.5 percent for a new wood-waste fired boiler that must meet a 0.1 pound per million British thermal unit (lb/MMBtu) PM emission limit. A wet ESP used to control PM emissions from a vertical stud Soderberg cell used in the electroreduction of aluminum ore achieved and average control efficiency of 96 percent (EPA, 1973b).

The results of emissions test on three wet ESPs used to control emissions from wood chip dryers were identified (EPA, 1989). For one ESP, the average control efficiency was 90.47 percent and ranged from 88.19 to 92.66 percent for three test runs. For another wet ESP, the average control efficiency was 94.81 percent and ranged from 94.64 to 96.60 percent for four test runs. For a third wet ESP, the average control efficiency was 85.40 percent and ranged from 68.7 to 96.4 percent for three test runs.

For two of the ESPs, the control efficiency for total nonmethane organic gases (TNMOG) and formaldehyde were tested. For one unit, the control efficiency for TNMOG averaged 69.95 percent and ranged from 54.51 to 86.89 percent for three test runs. The control efficiency for formaldehyde averaged 52.18 percent and ranged from 45.02 to 62.13 percent for three test runs. For the other unit, the control efficiency for TNMOG averaged 56.90 percent and ranged from 52.30 to 77.20 percent for three test runs. The control efficiency for formaldehyde averaged 1.30 percent and ranged from -12.00 to 16.7 percent for three test runs. Based on this data, the efficiency range for TNMOG is estimated to be 50 to 70 percent.

Wet ESPs are also used in the wool fiberglass insulation manufacturing industry to control emissions from forming, curing, and cooling operations. Test results for four ESPs indicated that average PM control efficiencies ranged from 78 to 93 percent, average formaldehyde control efficiencies ranged from 78 to 83 percent, average phenolic compound control efficiencies ranged from 62 to 93 percent, and average phenol control efficiencies ranged from 1 to 40 percent (EPA, 1983).

Based on these data, 80 percent was selected to represent the low-end of the range for PM. Based on professional judgment, the low-end control efficiencies for PM10 and PM2.5 were estimated to be 75 and 70 percent. The high-end control efficiencies for PM, PM10, and PM2.5 are based on those specified for dry ESPs.

Typical new equipment design efficiencies are between 99 and 99.9 percent. Older existing equipment has a range of actual operating efficiencies of 90 to 99.9 percent. While several factors determine ESP collection efficiency, ESP size is most important. Size determines treatment time; the longer a particle spends in the ESP, the greater its chance of being collected. Maximizing electric field strength will maximize ESP collection efficiency (STAPPA/ALAPCO, 1996). Collection efficiency is also affected to some extent by dust resistivity, gas temperature, chemical composition (of the dust and the gas), and particle size distribution.

Monitoring Parameters

Flue gas temperature, **voltage, current**, PM loading, flue gas flow rate, conditioning agents if used, and water supply

Typical inlet concentrations to a wire-pipe ESP are 1 to 10 grams per cubic meter (g/m3) (0.5 to 5 gr/ft3). It is common to pretreat a waste stream, usually with a wet spray or scrubber, to bring the stream temperature and pollutant loading into a manageable range. Highly toxic flows with concentrations well below 1 g/m3 (0.5 gr/ft3) are also sometimes controlled with ESPs. Wet wire-pipe ESPs are limited to operating at temperatures lower than approximately 80 to 90°C (170 to 190°F) (EPA, 2003). Other Considerations: dust resistivity is not a factor for wet ESPs, because of the high humidity atmosphere which lowers the resistivity of most materials. Particle size is much less of a factor for wet ESPs, compared to dry ESPs. Much smaller particles can be efficiently collected by wet ESPs due to the lack of resistivity concerns and the reduced re-entrainment (EPA, 2003).

Record Keeping Requirements

Continuous recording of flue gas temperature, voltage, current, PM loading, flue gas flow rate; daily recording of conditioning agent(s) and water supply rates.

Wet Rotoclone

Description

The RotoClone cleans the air by the combined action of centrifugal force and a thorough intermixing of water and dust-laden air. The dust is separated from the air by a water curtain, created by the flow of air through a partially submerged stationary impeller. Air flowing through the impeller at a high velocity conveys a turbulent sheet of water with it. Additional water is introduced at the narrowest portion of the impeller opening through a specially designed slot in the bottom. This water flow upward through the slot creates increased interaction between the dust and water, thus increasing collection efficiency.

The centrifugal force exerted by rapid changes in direction of flow causes the dust particles to penetrate the water film and become permanently trapped.

The water in the reservoir is continually used. Since the water curtain is produced by the airflow, no pumps or nozzles are required. A small amount of fresh water is supplied through the make-up water connection, to compensate for evaporation and water lost as the collected dust is removed from the unit.

There has no applicable control device code for this device from EPA. Pechan, thus, assigned a new code 504 to this device.

Control Efficiency:

Efficient operation is possible on a wide range of materials and particle sizes, including the small micron range. The unique airfoil design impeller provides such complete scrubbing of the dust laden air that fine particles are thoroughly wetted, expanding their mass. This increased mass makes the particles susceptible to the centrifugal forces acting upon them. This enables the particles to penetrate the water film and precipitate out of the air stream. Collection efficiencies of some types of RotoClone are equal to or better than any wet dust collector in the industry with comparable energy consumption.

Information from the U.S. Bureau of Mines indicates that the system is capable of reducing PM emissions by 92 percent (DOI, 1994). This was for an application on coal mine drilling equipment. The information referred to "respirable dust," which is assumed to be equivalent to PM10. The 92 percent value was selected as the typical efficiency for both total PM and PM10. No data were found for the potential range in control efficiencies or the efficiencies for PM2.5.

Monitoring Parameters:

Supply water depth, pressure drop, and flue gas flow rate.

Record-Keeping Requirements:

Recording of water level, flue gas flow rate and pressure drop every 24 hours.

Wet Scrubber (General, Not Classified)

Wet scrubbers are capable of removing gaseous and particulate contaminants from effluent gas streams. In wet scrubbers, the gas stream is contacted with liquid droplets or liquid in the form of wetted walls, liquid sheets, etc. The liquid/water entraps pollutants from the gas phase to the liquid phase. Air pollutants are removed by inertial or diffusional impaction, reaction with a sorbent or reagent slurry, or absorption into liquid solvent. Wet scrubbers are commercially available in many different designs, with pressure drops from 1.5 inch water gauge (in.wg) to as much as 100 in.wg. There is a corresponding variation in collector performance. It is generally accepted that, for well-designed equipment, control efficiency is dependent on the energy utilized in air to water contact and is independent of operating principle.

The applicable EPA control device codes for this category are 001 (Wet Scrubber - High Efficiency), 002 (Wet Scrubber - Medium Efficiency), 003 (Wet Scrubber - Low Efficiency), 129 (Scrubber), 141 (Wet Scrubber), and 155 (Packed bed Scrubber - High Efficiency). Pechan used the code 141 (Wet Scrubber) in the controls database for general wet scrubbers (no additional detail on device configuration). There was no method to specify control efficiencies for – High Efficiency, Medium Efficiency and Low Efficiency scrubbers as defined in the EPA table, nor are there any data in the literature that allow for a distinction of wet scrubbers by specific design criteria from which control efficiency could be inferred.

For PM Control

Description

This control equipment code applies in situations when the type of scrubber is unknown, different than, or a modification of other wet scrubbers presented in this report. [When used specifically for the control of sulfur dioxide (SO_2), the term flue-gas desulfurization (FGD) may also be used (EPA, 2003).]

Application

Wet scrubbers can be applied to a wide variety of emission sources in many industries because they can collect basically any type of particulate matter (PM), including flammable, explosive, moist, or sticky dusts. Although scrubbers have many potential applications, there are some limitations to their use. The most significant consideration is the relatively low collection efficiency for fine PM [i.e., <1 micrometers (μm)]. Therefore, conventional scrubbers may not be suitable for controlling flue gas streams with a high concentration of fine PM. Venturi, condensation, and charged scrubbers are the exception to this limitation because they are designed to achieve a high control of fine PM. In addition, the use of wet scrubbers may not be desirable when the collected dust can be recycled or sold as a dry product or when the gas stream contains constituents that will corrode the scrubber. Because of design constraints, wet scrubbers are generally not used to control large gas flow rates [e.g., >60,000 to 75,000 actual cubic feet per minute (cfm)], because large gas flow rates must be controlled with more than one scrubber.

References

AirScience, 1996. AirScience Technologies, "Biofiltration of Gaseous Effluents," AirScience Technologies Internet Web Page, www.enviroacess.ca/fiches_2/F2-04-96ba.html , 1996.

ASHRAE Standard 52.2, 1999, *"Method of Testing General Ventilation Air-Cleaning Devices for Removal Efficiency by Particle Size,"* http://xp20.ashrae.org/STANDARDS/availdft.htm

AWMA, 1992. Air & Waste Management Association, *Air Pollution Engineering Manual*, Van Nostrand Reinhold, New York.

Apel, W.A., J.M. Barnes, and K.B. Barrett, "Biofiltration of Nitrogen Oxides from Fuel Combustion Gas Streams," Proceedings of AWMA conference, June 18.

Billings, 1970. Billings, Charles, et al, *Handbook of Fabric FIlter Technology Volume I: Fabric Filter Systems Study*, GCA Corp., Bedford MA, December.

Budin and Kratz, 1995. M. Budin and R. Kratz, "Thermal Oxidizer Modifications for Enhanced Control of VOC Emissions," RMT/Four Nines, 1995.

Buonicore, 1992. Air and Waste Management Association, edited by Anthony J. Buonicore, and Wayne Davis, *Air Pollution Engineering Manual*, Van Nostrand Reinhold, New York, NY, 1992.

CARB, 1997b. California Air Resources Board BACT Clearinghouse Database -- "Storage Tanks - Organic Liquids."

CARB, 1997a. California Environmental Protection Agency, Air Resources Board, Stationary Source Division and Mobil Source Control Division, "Sources and Control of Oxides of Nitrogen Emissions," Sacramento, CA, August 1997.

CARB, 1999. California Environmental Protection Agency, Air Resources Board, Research Division, "Biofilter Technology for NOx Control," Report Number 96-304, Sacramento, CA, February.

Carr, 1984. Carr, R. C. and W. B. Smith, Fabric Filter Technology for Utility Coal-Fired Power Plants, Part V: Development and Evaluation of Bag Cleaning Methods in Utility Baghouses, J. Air Pollution Control Assoc., 34(5):584, May.

Chen, 1996. J. Chen, "Lower Operating Temperatures Oxidize VOCs," *Pollution Engineering*, December 1996.

Cooper and Alley, 1994. Cooper, C.D., and F.C. Alley, *Air Pollution Control: A Design Approach*, 2nd Edition, Waveland Press, Prospect Heights, IL, 1994.

Davis and Zeiss, 1997. R. Davis and R. Zeiss, "Low Temperature Cryogenic Condensation for Controlling VOC Emissions," presented at the 47th Annual CPI Exposition, New York, NY, November 19, 1997.

DOI, 1994. U.S. Department of Interior, Department of Mines, "Improved Dust Control for Surface Coal Mine Drills with Rotoclone Collectors," Technology News #440, October 1994.

DOE, 1995. U.S. Department of Energy, "Innovative Technology Summary - Flameless Thermal Oxidation," U.S. Department of Energy Internet Web Page, em.doe.gov/plumesfa/intech/fto/index.html, September 1995.

du Plessis et al. 1996. du Plessis, Chris, K.A. Kinney, E.D. Schroeder, D.P.Y. Chang, and K.M. Scow, "Anaerobic Activity in an Aerobic, Aerosol", 1996.

EPA, 1973a. U.S. Environmental Protection Agency, "Air Pollution Engineering Manual," Office of Air Quality Planning and Standards, Research Triangle Park, NC, AP-40 Second Edition, May 1973.

EPA, 1973b. U.S. Environmental Protection Agency, *National Emissions Data System Control Device Workbook*, APTD-1570, Research Triangle Park, NC, July 1973.

EPA, 1981. U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, "Control Techniques for Sulfur Oxide Emissions from Stationary Sources," Second Edition, Research Triangle Park, NC, April 1981.

EPA, 1982. U.S. Environmental Protection Agency, *Control Techniques for Particulate Emissions from Stationary Sources, Volume I*, EPA-450/3-81-005a, Research Triangle Park, NC, September 1982.

EPA, 1983. U.S. Environmental Protection Agency, *Wool Fiberglass Insulation Manufacturing Industry - Background Information for Proposed Standards*, EPA-450/3-83-022a, Research Triangle Park, NC, December 1983.

EPA, 1989. U.S. Environmental Protection Agency, *Evaluation of Emission Control Devices at Waferboard Plants*, EPA-450/3-90-002, Control Technology Center, Research Triangle Park, NC, October 1989.

EPA, 1991a. U.S. Environmental Protection Agency, Office of Research and Development, *Handbook - Control Technologies for Hazardous Air Pollutants*, EPA/625/6-91/014, Washington, DC, June 1991.

EPA, 1991b. U.S. EPA Office of Air Quality Planning and Standards. *Alternative Control Techniques Document – Nitric and Adipic Acid Manufacturing Plants*. December 1991.

EPA, 1992b. U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, "Control Techniques for Volatile Organic Compound Emissions from Stationary Sources," EPA 453/R-92-018, Washington, DC, December 1992.

EPA, 1992c. U.S. Environmental Protection Agency, *Hazardous Air Pollutant Emissions from Process Units in the Synthetic Organic Chemical Manufacturing Industry - Background Information for Proposed Standards, Volume 1B: Control Technologies*, Research Triangle Park, NC, November 1992.

EPA, 1992a. U.S. Environmental Protection Agency, Office of Air and Radiation, Office of Air Quality Planning and Standards; *Summary of NOx Control Technologies and their Availability ad Extent of Application*, Research Triangle Park, NC, February 1992.

EPA, 1993a. U.S. Environmental Protection Agency, *Chromium Emissions from Chromium Electroplating and Chromic Acid Anodizing Operations -- Background Information for Proposed Standards*, Volume I, EPA-450/3-93-030a, Research Triangle Park, NC, July 1993.

EPA, 1993b. U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards; *Alternative Control Techniques Document, NOx Emissions from Stationary Reciprocating Internal Combustion Engines*, Research Triangle Park, NC, July 1993.

EPA, 1994. United States Environmental Protection Agency, Office of Air Quality Planning and Standards; *Alternative Control Techniques Document, NOx Emissions from Utility Boilers*, Research Triangle Park, NC, March 1994.

EPA, 1995b. U.S. Environmental Protection Agency, Compilation of Air Pollutant Emission Factors, AP-42, Volume I, Fifth Edition, Research Triangle Park, NC, January 1995.

EPA, 1995a. U.S. EPA, Office of Air Quality Planning and Standards, "Survey of Control Technologies for Low Concentration Organic Vapor Gas Streams," EPA-456/R-95-003, Research Triangle Park, NC. May.

EPA, 1996a. U.S. EPA, Office of Air Quality Planning and Standards, "OAQPS Control Cost Manual," Fifth Edition, EPA 453/B-96-001, Research Triangle Park, NC. February.

EPA, 1996b. U.S. Environmental Protection Agency, 1990 National Inventory, Research Triangle Park, NC, January 1996.

EPA, 1998. U.S. EPA, Office of Air Quality Planning and Standards, "Stationary Source Control Techniques Document for Fine Particulate Matter," EPA-452/R-97-001, Research Triangle Park, NC, October.

EPA, 2000. EPA Control Cost Manual, Sixth Edition, Section 3.2 VOC Destruction Controls, Chapter 1 Flares. September, 2000.

EPA, 2001. U.S. EPA, Office of Air Quality Planning and Standards. *Refrigerated Condensers for Control of Organic Air Emissions*. December, 2001.

EPA, 2002. EPA Air Pollution Control Cost Manual - Sixth Edition, Section 3.2 VOC Destruction Controls, Chapter 2 Incinerators. July, 2002.

EPA, 2003. CATC Technical Bulletins(TB) & Air Pollution Technology Fact Sheets (FS), July 15, 2003.

FRTR, 1995. Federal Remediation Technologies Roundtable, "Remedial Technologies Screening Matrix and Reference Guide," (NTIS PB95-104782), edited by A. Loncar, prepared for U.S. Department of Defense, Federal Remediation Technologies Roundtable Internet Web Page, www.pipes.ehsg.saic.com/ top_page.html, 1995.

Gay, 1997. R. Gay, "In Search of the Best Control for Volatile Organics," *Environmental Technology*, May/June 1997.

Grossman, 1997. M. Grossman, Croll Reynolds (908-232-4200), personal communication with E. Albright, E.H. Pechan & Associates, Inc., December 2, 1997.

Harrison, 1996. L. Harrison, "Biofiltration: A New Alternative for VOC and Odor Control," Malcolm Pirnie Internet Web Page, www.pirnie.com/readings/air_crnt/ ac0696_5.htm, 1996.

Herbert, 1993. K. Herbert, "Catalytic Oxidation for VOCs," *The National Environmental Journal,* March/April 1993.

Hohl and Baer, 1997. H. Hohl and C. Baer, "Flameless Thermal Oxidation for Control of Aerosol Can Filling Emissions," *Environmental Technology*, November/December 1997.

ICAC, 1999. Institute of Clean Air Companies internet web page www.icac.com, Control Technology Information - Fabric Filters, page last updated January 11, 1999.

IEA, 1989. IEA Coal Research, "Reviews in Coal Science: The Problems of Sulfur," Butterworths, London, 1989.

Kittrell and Quinlan, 1995. J. Kittrell and C. Quinlan, "Air Stripping and Photocatalytic Oxidation -- A Winning Team for Groundwater Remediation," *Environmental Protection*, September 1995.

Kittrell, 1997. J. Kittrell, KSE, Inc. (413-549-5506), personal communication with J. Reisman, E.H. Pechan & Associates, Inc., December 18, 1997.

Leson and Winer, 1991. G. Leson and A. Winer, "Biofiltration: An Innovative Air Pollution Control Technology for VOC Emissions," *Journal of the Air and Waste Management Association*, August 1991.

McIlvaine, 1995. The McIlvaine Company, *The Scrubber Manual (Revised)*, Northbrook, IL, January 1995.

McIlvaine, 1996. The McIlvaine Company, *The Electrostatic Precipitator Manual (Revised)*, Northbrook, IL, March 1996.

Merrick, 1989. D. Merrick and J. Vernon, "Review of Flue Gas Desulfurization Systems," Chemistry and Industry, February 6, 1989.

NJDEP, 2003. New Jersey Department of Environmental Protection, *State of the Art (SOTA) Manual for Reciprocating Internal Combustion Engines*, http://www.state.nj.us/dep/aqpp, 2003.

Perry and Green, 1984. "Perry=s Chemical Engineers' Handbook," edited by R. Perry and D. Green, McGraw-Hill, New York NY, 1984.

Pollution Engineering, 1996. Pollution Engineering, "Lighter Air Without Lighting," *Pollution Engineering*, July 1996.

Power, 1996. Power Online, "Combu-Changer Regenerative Thermal-oxidizer System Provides Phased Low-solvent VOC Abatement," Power Online Internet Web Page, www.poweronline.com/case-studies/cs121296.html, December 12, 1996.

Public Works, 1997. Public Works Online, "Thermal Oxidation Provides One Answer to VOC Emission Problems," edited by I. Lisk, Public Works Online Internet Web Page, www.news.publicworks.com/feature-articles/fa70404.html, April 10, 1997.

Reimers and Gross, 1996. R. Reimers and M. Gross, "Covering All the Bases," *Environmental Protection*, April 1996.

Renko, 1994. R. Renko, "Thermal Treatment Puts a Cap on VOCs," *Pollution Engineering*, April 1994.

RTI, 1995. Research Triangle Institute, "Survey of Control Technologies for Low Concentration Organic Vapor Gas Streams," EPA-456/R-95-003, prepared for U.S. Environmental Protection Agency, Control Technology Center, Research Triangle Park, NC, May 1995.

Ruhl, 1994. M.J. Ruhl, "Is Solvent Recovery the Right Choice?" *Environmental Protection*, February 1994.

Satriana, 1981. Edited by M.J. Satriana, "New Developments in Flue Gas Desulfurization Technology," Noyes Data Corporation, Park Ridge, NJ, 1981.

Schrieber, 2005. Schrieber, M. of IAS Dust Collectors, Inc. personal communication with Ying Hsu of E.H. Pechan & Associate, Inc., May 3, 2005.

Smith, 1994. Irene M. Smith, Hermine N. Soud, and Mitsuru Takeshita, "Flue Gas Desulfurization for Coal-Fired Power Generation in the Asia-Pacific Region: An Overview of Best Available Options," from "The Clean and Efficient Use of Coal and Lignite: Its Role in Energy, Environment and Life," Organisation for Economic Co-Operation and Development/International Energy Agency, Paris, France, 1994.

Sondreal, 1993. Everett A. Sondreal, "Clean Utilization of Low-Rank Coals for Low-Cost Power Generation," from "Clean and Efficient Use of Coal: The New Era for Low-Rank Coal," Organisation for Economic Co-Operation and Development/International Energy Agency, Paris, France, 1993.

Soud, 1993. Hermine N. Soud, Mitsuru Takeshita, and Irene M. Smith, "FGD Systems and Installations for Coal-Fired Plants," from "Desulfurization 3," Institution of Chemical Engineers, Warwickshire, UK, 1993.

Standefer, 1996. S. Standefer, "Evaluating Biofiltration," *Environmental Technology*, July/August 1996.

STAPPA/ALAPCO, 1994. State and Territorial Air Pollution Program Administrators and Association of Local Air Pollution Control Officials, *Controlling Nitrogen Oxides Under Clean Air Act: A Menu of Options*, Washington, DC, July 1994.

STAPPA/ALAPCO, 1996. State and Territorial Air Pollution Program Administrators/ Association of Local Air Pollution Control Officials, *Controlling Particulate Matter Under the Clean Air Act: A Menu of Options*, July 1996.

Strommen, 1993. Svein Ole Strommen and Frank Hjelm, *"Sulphur in Flue Gases Can Safely Be Absorbed by Seawater and Returned to the Oceans,"* from "Desulfurization 3," Institution of Chemical Engineers Symposium Series No. 131, Warwickshire, UK, 1993.

Sun et al., 1994. Sun, J., B.Y.H. Liu, P.H. McMurry, and S. Greenwood, AA Method to Increase Control Efficiencies of Wet Scrubbers for Submicron Particles and Particulate Metals, *Journal of the Air & Waste Management Association*, 44:2, February 1994.

Theodore and Buonicore, 1988. L. Theodore and A. Buonicore, "Air Pollution Control Equipment - Volume II - Gases," CRC Press, Inc., Boca Raton, FL, 1988.

Torrens, 1990. Ian M. Torrens, "Environment," Vol. 32, No. 6, July/August 1990.

TRC, 1993. TRC Environmental Corporation, "Locating and Estimating Air Emissions from Sources of Toluene - Final Report" prepared for U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Research Triangle Park, NC, September 1993.

U.S. Filter, 1997. U.S. Filter Engineering Systems, "The Key to Low-cost Catalytic VOC/HAP Control," U.S. Filter Engineering Systems Internet Web Page www.usfiltereng.com/prodinfo/voccontr/areconab.htm, 1997.

Vatavuk, 1990. Vatavuk, W.M., *Estimating the Costs of Pollution Control*, Lewis Publishers, Chelsea, MI, 1990.

Vembu and Walker, 1995. K. Vembu and C. Walker, "Biofiltration Holds VOCs, Odors at Bay," *Environmental Protection*, February 1995.

Wani et al., 1997. A. Wani, R. Branion, and A. Lau, "Biofiltration: A Promising and Cost-Effective Control Technology for Odors, VOCs, and Air Toxics," *Journal of Environmental Science and Health, Part A - Environmental Science and Engineering & Toxic and Hazardous Substance Control,* Vol. A32:7, 1997.

Zeiss and Ibbetson, 1997. R. Zeiss and C. Ibbetson, "Cryogenic Condensation Puts a Chill on VOCs," *Pollution Engineering*, September 1997.

APPENDIX B. TAP LIST AND ASSOCIATED CATEGORIES

			Pollutant Type			
Pollutant	**CAS**		**VOT**	**POT**	**PIT**	**GIT**
Formaldehyde	50-00-0	50000	1*			
Phenobarbital	50-06-6	50066		1		
Benzo[a]pyrene	50-32-8	50328	2	1		
Reserpine	50-55-5	50555		1		
2,4-Dinitrophenol	51-28-5	51285	1			
Ethyl carbamate (Urethane)	51-79-6	51796	1			
Dibenz[a,h]anthracene	53-70-3	53703	2	1		
2-Acetylaminofluorene	53-96-3	53963		1		
N-Nitrosodiethylamine	55-18-5	55185		1		
Carbon tetrachloride	56-23-5	56235	1			
Parathion	56-38-2	56382		1		
3-Methylcholanthrene	56-49-5	56495		1		
Benz[a]anthracene	56-55-3	56553	2	1		
Chloramphenicol	56-75-7	56757		1		
1,1-Dimethylhydrazine	57-14-7	57147	1			
beta-Propiolactone	57-57-8	57578	1			
Chlordane	57-74-9	57749		1		
Progesterone	57-83-2	57832		1		
7,12-Dimethylbenz[a]anthracene	57-97-6	57976	2	1		
Lindane	58-89-9	58899		1		
N-Nitrosomorpholine	59-89-2	59892		1		
4-Dimethylaminoazobenzene	60-11-7	60117		1		
Methyl hydrazine	60-34-4	60344	1			
Acetamide	60-35-5	60355	1			
Niridazole	61-57-4	61574		1		
Amitrole	61-82-5	61825	1			
Aniline	62-53-3	62533	1			
Thioacetamide	62-55-5	62555		1		
Thiourea	62-56-6	62566		1		
Dichlorvos	62-73-7	62737	1			
N-Nitrosodimethylamine	62-75-9	62759		1		
Carbaryl	63-25-2	63252		1		
Diethyl sulfate	64-67-5	64675	1			
Cycloheximide	66-81-9	66819		1		
Methanol	67-56-1	67561	1			
Isopropyl alcohol	67-63-0	67630	1			
Acetone	67-64-1	67641	1			
Chloroform	67-66-3	67663	1			
Hexachloroethane	67-72-1	67721	1			
N,N-Dimethylformamide	68-12-2	68122	1			
n–Butyl alcohol	71-36-3	71363	1			
Benzene (including benzene from gasoline)	71-43-2	71432	1			
Methyl chloroform (1,1,1-Trichloroethane)	71-55-6	71556	1			
Methoxychlor	72-43-5	72435		1		
1,1-dichloro-2,2-bis (p-chlorophenyl) ethylene	72-55-9	72559		1		
Methyl bromide (Bromomethane)	74-83-9	74839	1			

			Pollutant Type			
Pollutant	**CAS**		**VOT**	**POT**	**PIT**	**GIT**
Ethylene	74-85-1	74851	1			
Methyl chloride (Chloromethane)	74-87-3	74873	1			
Methyl iodide (Iodomethane)	74-88-4	74884		1		
Hydrocyanic acid	74-90-8	74908	1			
Ethyl chloride (Chloroethane)	75-00-3	75003	1			
Vinyl chloride	75-01-4	75014	1			
Acetonitrile	75-05-8	75058	1			
Acetaldehyde	75-07-0	75070	1			
Methylene chloride (Dichloromethane)	75-09-2	75092	1			
Carbon disulfide	75-15-0	75150	1			
Ethylene oxide	75-21-8	75218	1			
Bromoform	75-25-2	75252	1			
Ethylidene dichloride (1,1-Dichloroethane)	75-34-3	75343	1			
Vinylidene chloride (1,1-Dichloroethylene)	75-35-4	75354	1			
Phosgene	75-44-5	75445	1			
1,2-Propylenimine (2-Methylaziridine)	75-55-8	75558	1			
Propylene oxide	75-56-9	75569	1			
tert–Butyl alcohol	75-65-0	75650	1			
Chloropicrin	76-06-2	76062	1			
Chlorinated fluorocarbon	76-13-1	76131	1			
Heptachlor	76-44-8	76448		1		
Hexachlorocyclopentadiene	77-47-4	77474	2	1		
Dimethyl sulfate	77-78-1	77781	1			
Triorthocresyl phosphate	78-30-8	78308		1		
Triethyl phosphine	78-40-0	78400	1			
Isophorone	78-59-1	78591	1			
Propylene dichloride (1,2-Dichloropropane)	78-87-5	78875	1			
sec–Butyl alcohol	7-89-22	78922	1			
Methyl ethyl ketone (2-Butanone)	78-93-3	78933	1			
1,1,2-Trichloroethane (Vinyl trichloride)	79-00-5	79005	1			
Trichloroethylene	79-01-6	79016	1			
Acrylamide	79-06-1	79061	1			
Acrylic acid	79-10-7	79107	1			
Chloroacetic acid	79-11-8	79118		1		
Peracetic acid	79-21-0	79210		1		
1,1,2,2-Tetrachloroethane	79-34-5	79345	1			
Dimethylcarbamoyl chloride	79-44-7	79447	1			
2-Nitropropane	79-46-9	79469	1			
4-4'-Isopropylidenediphenol	80-05-7	80057		1		
Cumene hydroperoxide	80-15-9	80159	1			
Methyl methacrylate	80-62-6	80626	1			
Pentachloronitrobenzene (Quintobenzene)	82-68-8	82688		1		
Dibutyl phthalate	84-74-2	84742		1		
Butyl benzyl phthalate	85-68-7	85687		1		
Hexachlorbutadiene	87-68-3	87683	1			

			Pollutant Type			
Pollutant	**CAS**		**VOT**	**POT**	**PIT**	**GIT**
Pentachlorophenol	87-86-5	87865	2	1		
2,4,6-Trichlorophenol	88-06-2	88062	2	1		
o-Anisidine	90-04-0	90040	1			
2-Phenylphenol	90-43-7	90437	2	1		
Michler's ketone	90-94-8	90948	1	2		
Toluene-2, 6-diisocyanate	91-08-7	91087	2	1		
Naphthalene	91-20-3	91203	1			
Quinoline	91-22-5	91225		1		
3,3'-Dichlorobenzidine	91-94-1	91941		1		
Biphenyl	92-52-4	92524	1			
4-Aminobiphenyl	92-67-1	92671	1			
Benzidine	92-87-5	92875	1			
4-Nitrobiphenyl	92-93-3	92933		1		
Benzoyl peroxide	94-36-0	94360		1		
Dichlorophenoxyacetic acid (including salts and esters)	94-75-7	94757		1		
o-Xylene	95-47-6	95476	1			
o-Cresol	95-48-7	95487	1			
1,2-Dichlorobenzene	95-50-1	95501	1			
o-Toluidine	95-53-4	95534	1	2		
Trimethylbenzene	95-63-6	95636	2	1		
p-Chloro-o-toluidene	95-69-2	95692	1			
Toluene-2,4-diamine (2,4-Diaminotoluene)	95-80-7	95807		1		
4-Choro-o-phenylenediamine	95-83-0	95830		1		
2,4,5-Trichlorophenol	95-95-4	95954	2	1		
Styrene oxide	96-09-3	96093	1	2		
1,2-Dibromo-3-chloropropane	96-12-8	96128	1			
Ethylene thiourea	96-45-7	96457		1		
Benzotrichloride (benzoic trichloride)	98-07-7	98077	1			
Cumene	98-82-8	98828	1			
Acetophenone	98-86-2	98862	1			
Benzoyl chloride	98-88-4	98884	1			
Nitrobenzene	98-95-3	98953	1	2		
4-Nitrophenol	100-02-7	100027	2	1		
Terephthalic acid	100-21-0	100210		1		
Ethylbenzene	100-41-4	100414	1			
Styrene	100-42-5	100425	1	2		
Benzyl chloride	100-44-7	100447	1			
N-Nitrosopiperidine	100-75-4	100754		1		
Triphenyl phosphite	101-02-0	101020		1		
4,4'-Methylene bis (2-chloroaniline)	101-14-4	101144		1		
4,4'-Methylenediphenyl diisocyanate	101-68-8	101688		1		
4,4'-Methylenedianiline (and its dichloride)	101-77-9	101779	1	2		
Bis (2-ethylhexyl) adipate	103-23-1	103231		1		
Caprolactam	105-60-2	105602		1		
p-Xylene	106-42-3	106423	1			
p-Cresol	106-44-5	106445	1			
1,4-Dichlorobenzene (p-Dichlorobenzene)	106-46-7	106467	1			

Pollutant	CAS		Pollutant Type VOT	POT	PIT	GIT
p-Phenylenediamine	106-50-3	106503	1			
Quinone (p-Benzoquinone)	106-51-4	106514		1		
1,2-Epoxybutane	106-88-7	106887	1			
Epichlorohydrin (l-Chloro-2,3-epoxypropane)	106-89-8	106898	1			
Ethylene dibromide (1,2-Dibromoethane)	106-93-4	106934	1			
1,3-Butadiene	106-99-0	106990	1			
Acrolein	107-02-8	107028	1			
Allyl chloride	107-05-1	107051	1			
Ethylene dichloride (1,2-Dichloroethane)	107-06-2	107062	1			
Acrylonitrile	107-13-1	107131	1			
Ethylene glycol	107-21-1	107211	1			
Chloromethyl methyl ether (technical grade)	107-30-2	107302	1			
Propylene glycol monomethyl ether	107-98-2	107982	1			
Vinyl acetate	108-05-4	108054	1			
Methyl isobutyl ketone (Hexone)	108-10-1	108101	1			
Maleic anhydride	108-31-6	108316		1		
m-Xylene	108-38-3	108383	1			
m-Cresol	108-39-4	108394	1			
Propylene glycol monomethyl ether acetate	108-65-6	108656	1			
Toluene	108-88-3	108883	1			
Chlorobenzene	108-90-7	108907	1			
Phenol	108-95-2	108952	2	1		
Ethylene glycol monomethyl ether	109-86-4	109864	1			
Ethylene glycol monomethyl ether acetate	110-4-96	110496	1			
Hexane	110-54-3	110543	1			
Ethylene glycol dimethyl ether	110-71-4	110714	1			
Ethylene glycol monoethyl ether	110-80-5	110805	1			
Cyclohexane	110-82-7	110827	1			
Pyridine	110-86-1	110861	1			
Ethylene glycol monoethyl ether acetate	111-15-9	111159	1			
Glutaraldehyde	111-30-8	111308	1			
Diethanolamine	111-42-2	111422	1			
Dichloroethyl ether [Bis(2-chloroethyl)ether]	111-44-4	111444	1			
Diethylene glycol	111-46-6	111466	1			
Ethylene glycol monobutyl ether	111-76-2	111762	1			
Diethylene glycol monomethyl ether	111-77-3	111773	1			
Diethylene glycol monoethyl ether	111-90-0	111900	1			

				Pollutant Type		
Pollutant	**CAS**		**VOT**	**POT**	**PIT**	**GIT**
Diethylene glycol dimethyl ether	111-96-6	111966	1			
Diethylene glycol monobutyl ether	112-34-5	112345	1			
Triethylene gylcol dimethyl ether	112-49-2	112492	1			
Propoxur (Baygon)	114-26-1	114261		1		
Propylene	115-07-1	115071	1			
Dicofol	115-32-2	115322		1		
Triphenyl phosphate	115-86-6	115866		1		
Bis (2-ethylhexyl) phthalate	117-81-7	117817		1		
Hexachlorobenzene	118-74-1	118741	2	1		
3,3'-Dimethoxybenzidine	119-90-4	119904		1		
3,3'-Dimethylbenzidine (o-Tolidine)	119-93-7	119937		1		
Anthracene	120-12-7	120127	2	1		
p-Cresidine	120-71-8	120718	1			
Catechol	120-80-9	120809	1			
1,2,4-Trichlorobenzene	120-82-1	120821	2	1		
2,4-Dichlorophenol	120-83-2	120832	1			
2,4-Dinitrotoluene	121-14-2	121142	1			
Triethylamine	121-44-8	121448	1			
N,N-Dimethylaniline	121-69-7	121697	1			
1,2-Diphenylhydrazine	122-66-7	122667	2	1		
Hydroquinone	123-31-9	123319	1			
Propionaldehyde	123-38-6	123386	1			
1,4-Dioxane (1,4-Diethyleneoxide)	123-91-1	123911	1			
Griseofulvin	126-07-8	126078		1		
Tributyl phosphate	126-73-8	126738		1		
Chloroprene	126-99-8	126998	1			
Tetrachloroethylene (Perchloroethylene)	127-18-4	127184	1			
Dimethyl phthalate	131-11-3	131113	1			
Dibenzofuran	132-64-9	132649	2	1		
Captan	133-06-2	133062		1		
Chloramben	133-90-4	133904		1		
Cupferron	135-20-6	135206		1		
Nitrilotriacetic acid	139-13-9	139139		1		
Ethyl acrylate	140-88-5	140885	1			
Butyl acrylate	141-32-2	141322	1			
Ethyleneimine (Aziridine)	151-56-4	151564	1			
p-Nitrosodiphenylamine	156-10-5	156105		1		
Calcium cyanamide	156-62-7	156627		1		
Dibenzo[a,i]pyrene	189-55-9	189559	2	1		
Dibenzo[a,h]pyrene	189-64-0	189640	2	1		
Dibenzo[a,l]pyrene	191-30-0	191300	2	1		
Dibenzo[a,e]pyrene	192-65-4	192654	2	1		
Indeno [1,2,3,-cd] pyrene	193-39-5	193395		1		
Benzo[j]fluoranthene	205-82-3	205823	2	1		
Benzo[b]fluoranthene	205-99-2	205992	2	1		
Benzo[k]fluoranthene	207-08-9	207089	2	1		
Chrysene	218-01-9	218019	2	1		
Dibenz[a,j]acridine	224-42-0	224420	2	1		

Pollutant	CAS		VOT	Pollutant Type POT	PIT	GIT
7H-Dibenzo[c,g]carbazole	224-42-0	224420		1		
Dibenz[a,h]acridine	226-36-8	226368	2	1		
Benzofuran	271-89-6	271896	2	1		
Lead acetate	301-04-2	301042			1	
Hydrazine	302-01-2	302012				1
Nitrogen mustard N-oxide	302-70-5	302705	1	2		
Diazomethane	334-88-3	334883	1			
Nickel acetate	373-02-4	373024		1		
Metronidazole	443-48-1	443481		1		
Carbonyl sulfide	463-58-1	463581	1			
Chlorobenzilate (Ethyl-4,4'-dichlorobenzilate)	510-15-6	510156		1		
Trimethyl phosphate	512-56-1	512561		1		
2-Chloroacetophenone	532-27-4	532274	1			
4,6-Dinitro-o-cresol (including salts)	534-52-1	534521	1			
2,2,4-Trimethylpentane	540-84-1	540841	1			
1,3-Dichlorobenzene	541-73-1	541731	1			
1,3-Dichloropropene	542-75-6	542756	1			
Bis(chloromethyl) ether	542-88-1	542881	1			
Toluene-2, 4-diisocyanate	584-84-9	584849	2	1		
Vinyl bromide	593-60-2	593602	1			
Methyl mercury (Dimethylmercury)	593-74-8	593748	1	2		
2,6-Dinitrotoluene	606-20-2	606202	1			
2-Nitrofluorene	607-57-8	607578		1		
2,4-Diaminoanisole	615-05-4	615054	1			
Methyl isocyanate	624-83-9	624839		1		
Ethylene glycol diethyl ether	629-14-1	629141	1			
Diphenylhydantoin	630-93-3	630933		1		
Hexamethylphosphoramide	680-31-9	680319		1		
N-Nitroso-N-methylurea	684-93-5	684935		1		
Hexamethylene-1,6-diisocyanate	822-06-0	822060	1			
N-Nitrosodi-n-butylamine	924-16-3	924163		1		
N-Nitrosopyrrolidine	930-55-2	930552		1		
N-Nitrosodiethanolamine	1116-54-7	1116547		1		
1,3-Propane sultone	1120-71-4	1120714	1			
Decabromodiphenyl oxide	1163-19-5	1163195		1		
Nickelocene	1271-28-9	1271289			1	
Sodium hydroxide	1310-73-2	1310732			1	
Molybdenum trioxide	1313-27-5	1313275			1	
Nickel oxide	1313-99-1	1313991			1	
Zinc oxide	1314-13-2	1314132			1	
Phosphorus pentoxide	1314-56-3	1314563			1	
Cresol/Cresylic acid (mixed isomers)	1319-77-3	1319773	1			
Antimony trioxide	1327-33-9	1327339			1	
Xylenes (mixed isomers)	1330-20-7	1330207	1			
Asbestos	1332-21-4	1332214			1	
Chromium trioxide	1333-82-0	1333820			1	
Lead subacetate	1335-32-6	1335326		1		
Polychlorinated biphenyls	1336-36-3	1336363	2	1		

Pollutant	CAS		VOT	Pollutant Type POT	PIT	GIT
Aluminum oxide (fibrous forms)	1344-28-1	1344281			1	
Trifluralin	1582-09-8	1582098		1		
N-Nitrosodi-n-propylamine	1621-64-7	1621647		1		
Methyl tert-butyl ether	1634-04-4	1634044	1			
2,3,7,8-Tetrachlorodibenzo-p-dioxin	1746-01-6	1746016	2	1		
Direct Black 38 (benzidine-based dye)	1937-37-7	1937377		1		
Captafol	2425-06-1	2425061		1		
Direct Blue 6 (benzidine-based dye)	2602-46-2	2602462		1		
Ethylene glycol monopropyl ether	2807-30-9	2807309	1			
Nickel carbonate	3333-39-3	3333393		1		
5-Methylchrysene	3697-24-3	3697243		1		
1-Nitropyrene	5522-43-0	5522430		1		
Ammonium nitrate	6484-52-2	6484522			1	
Aluminum	7429-90-5	7429905			1	
Lead	7439-92-1	7439921			1	
Manganese	7439-96-5	7439965			1	
Mercury	7439-97-6	7439976				1
Nickel	7440-02-0	7440020			1	
Silver	7440-22-4	7440224			1	
Thallium	7440-28-0	7440280			1	
Antimony	7440-36-0	7440360			1	
Arsenic	7440-38-2	7440382			1	
Beryllium	7440-41-7	7440417			1	
Cadmium	7440-43-9	7440439			1	
Chromium	7440-47-3	7440473			1	
Cobalt	7440-48-4	7440484			1	
Copper	7440-50-8	7440508			1	
Zinc	7440-66-6	7440666			1	
Lead phosphate	7446-27-7	7446277			1	
Selenium sulfide	7446-34-6	7446346			1	
Mercuric chloride	7487-94-7	7487947			1	2
6-Nitrochrysene	7496-02-8	7496028		1		
Titanium tetrachloride	7550-45-0	7550450			1	
Hydrochloric acid [Hydrogen chloride (gas only)]	7647-01-0	7647010				1
Phosphoric acid	7664-382	7664382			1	
Hydrogen fluoride (Hydrofluoric acid)	7664-39-3	7664393				1
Ammonia	7664-41-7	7664417				1
Sulfuric acid	7664-93-9	7664939			1	2
Nitric acid	7697-37-2	7697372			2	1
Phosphorus trichloride	7719-12-2	7719122				1
Phosphorus	7723-14-0	7723140			1	
Bromine	7726-95-6	7726956				1
Barium	7740-39-3	7740393			1	
Potassium bromate	7758-01-2	7758012			1	
Lead chromate	7758-97-6	7758976			1	
Selenium	7782-49-2	7782492			1	
Chlorine	7782-50-5	7782505				1

				Pollutant Type		
Pollutant	**CAS**		**VOT**	**POT**	**PIT**	**GIT**
Hydrogen sulfide	7783-06-4	7783064				1
2-Aminoanthraquinone	7783-20-2	7783202		1		
Ammonium sulfate	7783-20-2	7783202			1	
Arsine	7784-42-1	7784421				1
Strontium chromate	7789-06-2	7789062			1	
Phosphine	7803-51-2	7803512				1
Toxaphene (polychlorinated camphenes)	8001-35-2	8001352		1		
Phosphorus oxychloride	10025-87-3	10025873				1
Phosphorus pentachloride	10026-13-8	10026138			1	2
Chlorine dioxine	10049-04-4	10049044				1
Barium chromate	10294-40-3	10294403			1	
Sodium dichromate	10588-01-9	10588019			1	
N-Nitrosomethylethylamine	10595-95-6	10595956		1		
Nickel subsulfide	12035-72-2	12035722			1	
Nickel hydroxide	12054-48-7	12054487			1	
Erionite	12510-42-8	12510428		1		
Nickel carbonyl	13463-39-3	13463393	1			
Calcium chromate	13765-19-0	13765190			1	
1-(2-Chloroethyl)-3- (4-methylcyclohexyl)-1-nitrosourea	13909-09-6	13909096		1		
Direct Brown 95 (technical grade) (benzidine-based dye)	16071-86-6	16071866		1		
Chromium (hexavalent) (and compounds)	18540-29-9	18540299			1	
1,2,3,7,8,9-Hexachlorodibenzo-p-dioxin	19408-74-3	19408743	2	1		
Iodine-131	24267-56-9	24267569				1
Dipropylene glycol	25265-71-8	25265718	1			
Dinitrotoluenes (mixed isomers)	25321-14-6	25321146	1			
Dichlorobenzenes (mixed isomers)	25321-22-6	25321226	1			
Dipropylene glycol monomethyl ether	34590-94-8	34590948	1			
1,2,3,4,6,7,8-Heptachlorodibenzo-p-dioxin	35822-46-9	35822469	2	1		
1,2,3,4,7,8-Hexachlorodibenzo-p-dioxin	39227-28-6	39227286	2	1		
1,2,3,7,8-Pentachlorodibenzo-p-dioxin	40321-76-4	40321764	2	1		
1,6-Dinitropyrene	42397-64-8	42397648		1		
1,8-Dinitropyrene	42397-65-9	42397659		1		
2,3,7,8-Tetrachlorodibenzofuran	51207-31-9	51207319	2	1		
1,2,3,4,7,8,9-Heptachlorodibenzofuran	55673-89-7	55673897	2	1		
2,3,4,7,8-Pentachlorodibenzofuran	57117-31-4	57117314	2	1		
1,2,3,7,8-Pentachlorodibenzofuran	57117-41-6	57117416	2	1		
1,2,3,6,7,8-Hexachlorodibenzofuran	57117-44-9	57117449	2	1		

Pollutant	CAS		Pollutant Type VOT	POT	PIT	GIT
1,2,3,6,7,8-Hexachlorodibenzo-p-dioxin	57653-85-7	57653857	2	1		
2,3,4,6,7,8-Hexachlorodibenzofuran	60851-34-5	60851345	2	1		
1,2,3,4,6,7,8-Heptachlorodibenzofuran	67562-39-4	67562394	2	1		
1,2,3,4,7,8-Hexachlorodibenzofuran	70648-26-9	70648269	2	1		
1,2,3,7,8,9-Hexachlorodibenzofuran	72918-21-9	72918219	2	1		
Chlorinated paraffins (average chain length, C12; approx. 60% chlorine by weight)	108171-26-2	108171262	1	2		
Selenium Compounds	n/a	n/a			1	
Radionuclides (including radon and its decay products)	n/a	n/a				see notes below**
Antimony Compounds	n/a	n/a			1	
Arsenic Compounds (other than inorganic)	n/a	n/a		1		
Benzidine-based Dyes	n/a	n/a		1		
Beryllium Compounds	n/a	n/a			1	
Bromine Compounds	n/a	n/a			1	2
Carbon Black Extracts	n/a	n/a		1		
Carrageenan	n/a	n/a		1		
Ceramic fibers	n/a	n/a			1	
Chlorophenols	n/a	n/a	1	2		
Copper Compounds	n/a	n/a			1	
Creosotes	n/a	n/a		1		
Dialkylnitrosamines	n/a	n/a	1			
Diaminotoluenes (mixed isomers)	n/a	n/a	2	1		
Dibenzofurans (chlorinated)	n/a	n/a	2	1		
Diesel Engine Exhaust	n/a	n/a	2	1		
Diesel Fuel (marine)	n/a	n/a	1			
Dioxins	n/a	n/a				
Environmental Tobacco Smoke	n/a	n/a	2	1		
Epoxy Resins	n/a	n/a	1	2		
Fluorocarbons (brominated)	n/a	n/a	1			
Fluorocarbons (chlorinated)	n/a	n/a	1			
Gasoline engine exhaust	n/a	n/a	1	2		
Gasoline engine exhaust (condensates and extracts)	n/a	n/a	2	1		
Gasoline vapors	n/a	n/a	1			
Glasswool fibers	n/a	n/a			1	
Hexachlorocyclohexanes (all stereo isomers, including lindane)	n/a	n/a	2	1		
Isocyanates	n/a	n/a	1			
Lead Compounds (inorganic)	n/a	n/a			1	
Lead Compounds (other than inorganic)	n/a	n/a		1		

			Pollutant Type			
Pollutant		**CAS**	**VOT**	**POT**	**PIT**	**GIT**
Nickel refinery dust from the pyrometallurgical process	n/a	n/a			1	
Phosphorus Compounds	n/a	n/a			1	
Polychlorinated dibenzo-p-dioxins	n/a	n/a				
Polychlorinated dibenzofurans	n/a	n/a				
Polycyclic Aromatic Hydrocarbons	n/a	n/a				
Polycyclic Aromatic Hydrocarbon Derivatives	n/a	n/a				
Polycyclic Organic Matter	n/a	n/a				
Residual (heavy) fuel oils	n/a	n/a		1		
Rockwool fibers	n/a	n/a			1	
Silica, crystalline	n/a	n/a			1	
Slagwool fibers	n/a	n/a			1	
Talc containing asbestiform fibers	n/a	n/a			1	
Thallium Compounds	n/a	n/a			1	
Toluene diisocyanates	n/a	n/a	1			
Vanadium (fume or dust)	n/a	n/a			1	
Wood preservatives (containing arsenic and chromate)	n/a	n/a	2	1		
Xylenes (mixed xylenes)	n/a	n/a	1			
Zinc Compounds	n/a	n/a			1	
Fluoride Compounds	n/a	n/a			1	
Phthalic anhydride	n/a	n/a	1			
Arsenic Compounds (inorganic including Arsine)	n/a	n/a			1	2
Cadmium Compounds	n/a	n/a			1	
Cobalt Compounds	n/a	n/a			1	
Coke Oven Emissions	n/a	n/a	1	2		
Cyanide Compoundsd	n/a	n/a			1	2
Glycol ethers and their acetatese	n/a	n/a	1			
Lead Compounds	n/a	n/a			1	
Mercury Compounds	n/a	n/a	2		2	1
Mineral fibers (fine)	n/a	n/a			1	
Nickel Compounds	n/a	n/a			1	
Manganese Compounds	n/a	n/a			1	
Chromium Compounds (other than hexavalent)	n/a	n/a			1	
Chlorobenzenes	n/a	n/a	1			

* For each air toxic, the pollutant type is indicated by a "1" in the appropriate VOT, POT, PIT, or GIT column. In some cases, a secondary type is indicated with a "2", if the pollutant is known to exist as both types within air pollutant streams. For example, many combustion products, such as dioxins, furans, and PAHs, are known to exist both in the vapor state (i.e., a VOT), as well as being bound to particulate matter (i.e., a POT).

** A type of atom which spontaneously undergoes radioactive decay. Although radionuclides are technically of the GIT type, none of the point source controls currently in the database are known to provide significant control of these pollutants.

MPCA Code	CONTROL DEVICE/METHOD	TE/NTE	Applicable EPA Codes	Device Description	PM			PM10			PM2.5			SOx			NOx	
					Low	High	Rep.	Low	High	Rep.	Low	High	Rep.	Low	High	Rep.	Low	High
	PM Controls:																	
501	Mechanically-aided Separator	TE	056, 113	056 (Dynamic Separator(Dry); 113 (Rotoclone)	30.0	99.0	64.5	0.0	10.0	5.0	0.0	5.0	2.5					
501	Mechanically-aided Separator	NTE	056, 113	056 (Dynamic Separator(Dry); 113 (Rotoclone)	24.0	79.2	51.6	0.0	8.0	4.0	0.0	4.0	2.0					
503	Charged Scrubber	TE	503	New Device	90.0	99.0	94.5	70.0	99.0	84.5	25.0	99.0	62.0					
503	Charged Scrubber	NTE	503	New Device	72.0	79.2	75.6	56.0	79.2	67.6	20.0	79.2	49.6					
517	Condensation Scrubber	TE	517	New Device	90.0	99.0	94.5	70.0	99.0	84.5	25.0	99.0	62.0					
517	Condensation Scrubber	NTE	517	New Device	72.0	79.2	75.6	56.0	79.2	67.6	20.0	79.2	49.6					
010	Dry Electrostatic Precipitator	TE	010, 011, 012, 128	010 (Electrostatic Precipitator - High Efficiency); 011 (Electrostatic Precipitator - Medium Efficiency); 012 (Electrostatic Precipitator - Low Efficiency); 128 (Electrostatic Precipitator)	99.0	99.9	99.5	97.0	99.5	98.3	96.0	99.0	97.5					
010	Dry Electrostatic Precipitator	NTE	010, 011, 012, 128	010 (Electrostatic Precipitator - High Efficiency); 011 (Electrostatic Precipitator - Medium Efficiency); 012 (Electrostatic Precipitator - Low Efficiency); 128 (Electrostatic Precipitator)	79.2	79.9	79.6	77.6	79.6	78.6	76.8	79.2	78.0					
146	Wet Electrostatic Precipitator	TE	146	146 (Wet Electrostatic Precipitator)	98.0	99.9	99.0	94.0	99.5	96.8	90.0	99.0	94.5					
146	Wet Electrostatic Precipitator	NTE	146	146 (Wet Electrostatic Precipitator)	78.4	79.9	79.2	75.2	79.6	77.4	72.0	79.2	75.6					
016	Fabric Filter (Pulse-jet, Reverse-air, Mechanical Shaker)	TE	016, 017, 018, 100, 127	016 (Fabric Filter - High Velocity, I.E. T>250F); 017 (Fabric Filter - Medium Temperature, I.E. 180F<T<250F); 018 (Fabric Filter - Low Temperature, I.E. T<180F); 100 (Baghouse); 127 (Fabric Filter)	90.0	99.9	95.0	85.0	99.9	92.5	80.0	99.9	90.0	15.0	30.0	22.5		
016	Fabric Filter (Pulse-jet, Reverse-air, Mechanical Shaker)	NTE	016, 017, 018, 100, 127	016 (Fabric Filter - High Velocity, I.E. T>250F); 017 (Fabric Filter - Medium Temperature, I.E. 180F<T<250F); 018 (Fabric Filter - Low Temperature, I.E. T<180F); 100 (Baghouse); 127 (Fabric Filter)	72.0	79.9	76.0	68.0	79.9	74.0	64.0	79.9	72.0	12.0	24.0	18.0		

MPCA			Applicable				CO			VOC			VOT			POT			PIT
Code	CONTROL DEVICE/METHOD	TE/NTE	EPA Codes	Device Description	Rep.	Low	High	Rep.	Low	High	Rep.	Low	High	Rep.	Low	High	Rep.	Low	High
	PM Controls:																		
501	Mechanically-aided Separator	TE	056, 113	056 (Dynamic Separator(Dry); 113 (Rotoclone)											0.0	10.0	5.0	0.0	10.0
501	Mechanically-aided Separator	NTE	056, 113	056 (Dynamic Separator(Dry); 113 (Rotoclone)											0.0	8.0	4.0	0.0	8.0
503	Charged Scrubber	TE	503	New Device											70.0	99.0	84.5	70.0	99.0
503	Charged Scrubber	NTE	503	New Device											56.0	79.2	67.6	56.0	79.2
517	Condensation Scrubber	TE	517	New Device											70.0	99.0	84.5	70.0	99.0
517	Condensation Scrubber	NTE	517	New Device											56.0	79.2	67.6	56.0	79.2
010	Dry Electrostatic Precipitator	TE	010, 011, 012, 128	010 (Electrostatic Precipitator - High Efficiency); 011 (Electrostatic Precipitator - Medium Efficiency); 012 (Electrostatic Precipitator - Low Efficiency); 128 (Electrostatic Precipitator)											96.0	99.0	97.5	96.0	99.0
010	Dry Electrostatic Precipitator	NTE	010, 011, 012, 128	010 (Electrostatic Precipitator - High Efficiency); 011 (Electrostatic Precipitator - Medium Efficiency); 012 (Electrostatic Precipitator - Low Efficiency); 128 (Electrostatic Precipitator)											76.8	79.2	78.0	76.8	79.2
146	Wet Electrostatic Precipitator	TE	146	146 (Wet Electrostatic Precipitator)					50.0	70.0	60.0	50.0	70.0	60.0	90.0	99.0	94.5	90.0	99.0
146	Wet Electrostatic Precipitator	NTE	146	146 (Wet Electrostatic Precipitator)					40.0	56.0	48.0	40.0	56.0	48.0	72.0	79.2	75.6	72.0	79.2
016	Fabric Filter (Pulse-jet, Reverse-air, Mechanical Shaker)	TE	016, 017, 018, 100, 127	016 (Fabric Filter - High Velocity, I.E. T>250F); 017 (Fabric Filter - Medium Temperature, I.E. 180F<T<250F); 018 (Fabric Filter - Low Temperature, I.E. T<180F); 100 (Baghouse); 127 (Fabric Filter)											80.0	99.9	90.0	80.0	99.9
016	Fabric Filter (Pulse-jet, Reverse-air, Mechanical Shaker)	NTE	016, 017, 018, 100, 127	016 (Fabric Filter - High Velocity, I.E. T>250F); 017 (Fabric Filter - Medium Temperature, I.E. 180F<T<250F); 018 (Fabric Filter - Low Temperature, I.E. T<180F); 100 (Baghouse); 127 (Fabric Filter)											64.0	79.9	72.0	64.0	79.9

MPCA Code	CONTROL DEVICE/METHOD	TE/NTE	Applicable EPA Codes	Device Description	Rep.	GIT Low	GIT High	Rep.	Monitoring Parameter(s)
	PM Controls:								
501	Mechanically-aided Separator	TE	056, 113	056 (Dynamic Separator(Dry); 113 (Rotoclone)	5.0				**Gas stream velocity and or pressure drop**
501	Mechanically-aided Separator	NTE	056, 113	056 (Dynamic Separator(Dry); 113 (Rotoclone)	4.0				**Gas stream velocity and or pressure drop**
503	Charged Scrubber	TE	503	New Device	84.5				Could monitor one or more of the following: **Liquid flow rate, pressure drop**, blowdown rate, electrical values (kV, mAmp), gas flow rate
503	Charged Scrubber	NTE	503	New Device	67.6				Could monitor one or more of the following: **Liquid flow rate, pressure drop**, blowdown rate, electrical values (kV, mAmp), gas flow rate
517	Condensation Scrubber	TE	517	New Device	84.5				**Pressure drop**, relative humidity, steam supply rate, blowdown rate, electrical values (kV, mAmp), gas flow rate
517	Condensation Scrubber	NTE	517	New Device	67.6				**Pressure drop**, relative humidity, steam supply rate, blowdown rate, electrical values (kV, mAmp), gas flow rate
010	Dry Electrostatic Precipitator	TE	010, 011, 012, 128	010 (Electrostatic Precipitator - High Efficiency); 011 (Electrostatic Precipitator - Medium Efficiency); 012 (Electrostatic Precipitator - Low Efficiency); 128 (Electrostatic Precipitator)	97.5				Flue gas temperature, **voltage, current**, PM loading, flue gas flow rate, conditioning agents if used
010	Dry Electrostatic Precipitator	NTE	010, 011, 012, 128	010 (Electrostatic Precipitator - High Efficiency); 011 (Electrostatic Precipitator - Medium Efficiency); 012 (Electrostatic Precipitator - Low Efficiency); 128 (Electrostatic Precipitator)	78.0				Flue gas temperature, **voltage, current**, PM loading, flue gas flow rate, conditioning agents if used
146	Wet Electrostatic Precipitator	TE	146	146 (Wet Electrostatic Precipitator)	94.5				Flue gas temperature, **voltage, current**, PM loading, flue gas flow rate, conditioning agents if used, and water supply
146	Wet Electrostatic Precipitator	NTE	146	146 (Wet Electrostatic Precipitator)	75.6				Flue gas temperature, **voltage, current**, PM loading, flue gas flow rate, conditioning agents if used, and water supply
016	Fabric Filter (Pulse-jet, Reverse-air, Mechanical Shaker)	TE	016, 017, 018, 100, 127	016 (Fabric Filter - High Velocity, I.E. T>250F); 017 (Fabric Filter - Medium Temperature, I.E. 180F<T<250F); 018 (Fabric Filter - Low Temperature, I.E. T<180F); 100 (Baghouse); 127 (Fabric Filter)	90.0				Gas stream **pressure drop**, flow rate, **opacity**, temperature, and dust removal
016	Fabric Filter (Pulse-jet, Reverse-air, Mechanical Shaker)	NTE	016, 017, 018, 100, 127	016 (Fabric Filter - High Velocity, I.E. T>250F); 017 (Fabric Filter - Medium Temperature, I.E. 180F<T<250F); 018 (Fabric Filter - Low Temperature, I.E. T<180F); 100 (Baghouse); 127 (Fabric Filter)	72.0				Gas stream **pressure drop**, flow rate, **opacity**, temperature, and dust removal

MPCA Code	CONTROL DEVICE/METHOD	TE/NTE	Applicable EPA Codes	Device Description	Record-keeping Requirements
	PM Controls:				
501	Mechanically-aided Separator	TE	056, 113	056 (Dynamic Separator(Dry); 113 (Rotoclone)	Daily recording of gas stream velocity and/or pressure drop
501	Mechanically-aided Separator	NTE	056, 113	056 (Dynamic Separator(Dry); 113 (Rotoclone)	Daily recording of gas stream velocity and/or pressure drop
503	Charged Scrubber	TE	503	New Device	Daily records of liquid flow rate, pressure drop, blowdown rate, electrical values (kV, mAmp), gas flow rate
503	Charged Scrubber	NTE	503	New Device	Daily records of liquid flow rate, pressure drop, blowdown rate, electrical values (kV, mAmp), gas flow rate
517	Condensation Scrubber	TE	517	New Device	Daily records of pressure drop, relative humidity, steam supply rate, blowdown rate, electrical values (kV, mAmp), gas flow rate
517	Condensation Scrubber	NTE	517	New Device	Daily records of pressure drop, relative humidity, steam supply rate, blowdown rate, electrical values (kV, mAmp), gas flow rate
010	Dry Electrostatic Precipitator	TE	010, 011, 012, 128	010 (Electrostatic Precipitator - High Efficiency); 011 (Electrostatic Precipitator - Medium Efficiency); 012 (Electrostatic Precipitator - Low Efficiency); 128 (Electrostatic Precipitator)	Recording of continuous flue gas temperature, voltage, current, PM loading, flow gas flow rate, and 24 hours of conditioning agents
010	Dry Electrostatic Precipitator	NTE	010, 011, 012, 128	010 (Electrostatic Precipitator - High Efficiency); 011 (Electrostatic Precipitator - Medium Efficiency); 012 (Electrostatic Precipitator - Low Efficiency); 128 (Electrostatic Precipitator)	Recording of continuous flue gas temperature, voltage, current, PM loading, flow gas flow rate, and 24 hours of conditioning agents
146	Wet Electrostatic Precipitator	TE	146	146 (Wet Electrostatic Precipitator)	Recording of continuous flue gas temperature, voltage, current, PM loading, flow gas flow rate,24 hours of conditioning agents and water supply
146	Wet Electrostatic Precipitator	NTE	146	146 (Wet Electrostatic Precipitator)	Recording of continuous flue gas temperature, voltage, current, PM loading, flow gas flow rate,24 hours of conditioning agents and water supply
016	Fabric Filter (Pulse-jet, Reverse-air, Mechanical Shaker)	TE	016, 017, 018, 100, 127	016 (Fabric Filter - High Velocity, I.E. T>250F); 017 (Fabric Filter - Medium Temperature, I.E. 180F<T<250F); 018 (Fabric Filter - Low Temperature, I.E. T<180F); 100 (Baghouse); 127 (Fabric Filter)	Monthly/quarterly cleaning intensity and frequency, dust removal; daily records of gas stream pressure drop, flow rate, opacity, and temperature
016	Fabric Filter (Pulse-jet, Reverse-air, Mechanical Shaker)	NTE	016, 017, 018, 100, 127	016 (Fabric Filter - High Velocity, I.E. T>250F); 017 (Fabric Filter - Medium Temperature, I.E. 180F<T<250F); 018 (Fabric Filter - Low Temperature, I.E. T<180F); 100 (Baghouse); 127 (Fabric Filter)	Monthly/quarterly cleaning intensity and frequency, dust removal; daily records of gas stream pressure drop, flow rate, opacity, and temperature

MPCA			Applicable		PM			PM10			PM2.5			SOx			NOx	
Code	CONTROL DEVICE/METHOD	TE/NTE	EPA Codes	Device Description	Low	High	Rep.	Low	High	Rep.	Low	High	Rep.	Low	High	Rep.	Low	High
	PM Controls:																	
519	Fabric Filter (Pulse-jet, Reverse-air, Mechanical Shaker) - Applied to Metal Fume Sources	TE	016, 017, 018, 100, 127	016 (Fabric Filter - High Velocity, I.E. T>250F); 017 (Fabric Filter - Medium Temperature, I.E. 180F<T<250F); 018 (Fabric Filter - Low Temperature, I.E. T<180F); 100 (Baghouse); 127 (Fabric Filter)	90.0	99.9	93.9	85.0	99.9	93.9	80.0	99.9	93.4					
519	Fabric Filter (Pulse-jet, Reverse-air, Mechanical Shaker) - Applied to Metal Fume Sources	NTE	016, 017, 018, 100, 127	016 (Fabric Filter - High Velocity, I.E. T>250F); 017 (Fabric Filter - Medium Temperature, I.E. 180F<T<250F); 018 (Fabric Filter - Low Temperature, I.E. T<180F); 100 (Baghouse); 127 (Fabric Filter)	72.0	79.9	75.1	68.0	79.9	75.1	64.0	79.9	74.7					
004	Gravity Collector (Expansion Chamber, Settling Chamber, Elutriators)	TE	004, 005, 006	004 (Gravity Collector - High Efficiency); 005 (Gravity Collector - Medium Efficiency); 006 (Gravity Collector - Low Efficiency)	10.0	99.0	54.5											
004	Gravity Collector (Expansion Chamber, Settling Chamber, Elutriators)	NTE	004, 005, 006	004 (Gravity Collector - High Efficiency); 005 (Gravity Collector - Medium Efficiency); 006 (Gravity Collector - Low Efficiency)	8.0	79.2	43.6											
058	Mat or Panel Filter (Conventional)	TE	058	058 (Mat or Panel Filter)	60.0	80.0	70.0	80.0	90.0	85.0								
058	Mat or Panel Filter (Conventional)	NTE	058	058 (Mat or Panel Filter)	48.0	64.0	56.0	64.0	72.0	68.0								
101	Mat or Panel Filter (High Efficiency, HEPA, ULPA)	TE	101	101 (High-Efficiency Particulate Air Filter (HEPA))	99.97	99.999	99.98	99.97	99.999	99.98	99.97	99.999	99.98					
101	Mat or Panel Filter (High Efficiency, HEPA, ULPA)	NTE	101	101 (High-Efficiency Particulate Air Filter (HEPA))	79.98	80.00	79.99	79.98	80.00	79.99	79.98	80.00	79.99					
057	Mechanically-Aided Scrubber	TE	057, 085	057 (Dynamic Separator (Wet)); 085 (Wet Cyclonic Separator)	70.0	99.0	84.5	70.0	99.0	84.5	25.0	97.0	61.0					
057	Mechanically-Aided Scrubber	NTE	057, 085	057 (Dynamic Separator (Wet)); 085 (Wet Cyclonic Separator)	56.0	79.2	67.6	56.0	79.2	67.6	20.0	77.6	48.8					
014	Mist Eliminator - Blade Type	TE	014, 015, 134, 151, 152	014 (Mist Eliminator - High Velocity, I.E. V>250 FT/MIN); 015 (Mist Eliminator - Low Velocity, I.E. V<250 FT/MIN); 134 (Demister); 151 (Fiber Mist Eliminator); 152 (Mist Eliminator - High Efficiency)	80.0	98.0	89.0	80.0	98.0	89.0	50.0	70.0	60.0					
014	Mist Eliminator - Blade Type	NTE	014, 015, 134, 151, 152	014 (Mist Eliminator - High Velocity, I.E. V>250 FT/MIN); 015 (Mist Eliminator - Low Velocity, I.E. V<250 FT/MIN); 134 (Demister); 151 (Fiber Mist Eliminator); 152 (Mist Eliminator - High Efficiency)	64.0	78.4	71.2	64.0	78.4	71.2	40.0	56.0	48.0					
015	Mist Eliminator - Mesh-Type	TE	014, 015, 134, 151, 152	014 (Mist Eliminator - High Velocity, I.E. V>250 FT/MIN); 015 (Mist Eliminator - Low Velocity, I.E. V<250 FT/MIN); 134 (Demister); 151 (Fiber Mist Eliminator); 152 (Mist Eliminator - High Efficiency)	95.0	99.0	97.0	95.0	99.0	97.0	90.0	99.0	94.5					

MPCA			Applicable		CO			VOC			VOT			POT			PIT		
Code	CONTROL DEVICE/METHOD	TE/NTE	EPA Codes	Device Description	Rep.	Low	High	Rep.	Low	High	Rep.	Low	High	Rep.	Low	High	Rep.	Low	High
	PM Controls:																		
519	Fabric Filter (Pulse-jet, Reverse-air, Mechanical Shaker) - Applied to Metal Fume Sources	TE	016, 017, 018, 100, 127	016 (Fabric Filter - High Velocity, I.E. T>250F); 017 (Fabric Filter - Medium Temperature, I.E. 180F<T<250F); 018 (Fabric Filter - Low Temperature, I.E. T<180F); 100 (Baghouse); 127 (Fabric Filter)											80.0	99.9	93.4	80.0	99.9
519	Fabric Filter (Pulse-jet, Reverse-air, Mechanical Shaker) - Applied to Metal Fume Sources	NTE	016, 017, 018, 100, 127	016 (Fabric Filter - High Velocity, I.E. T>250F); 017 (Fabric Filter - Medium Temperature, I.E. 180F<T<250F); 018 (Fabric Filter - Low Temperature, I.E. T<180F); 100 (Baghouse); 127 (Fabric Filter)											64.0	79.9	74.7	64.0	79.9
004	Gravity Collector (Expansion Chamber, Settling Chamber, Elutriators)	TE	004, 005, 006	004 (Gravity Collector - High Efficiency); 005 (Gravity Collector - Medium Efficiency); 006 (Gravity Collector - Low Efficiency)															
004	Gravity Collector (Expansion Chamber, Settling Chamber, Elutriators)	NTE	004, 005, 006	004 (Gravity Collector - High Efficiency); 005 (Gravity Collector - Medium Efficiency); 006 (Gravity Collector - Low Efficiency)															
058	Mat or Panel Filter (Conventional)	TE	058	058 (Mat or Panel Filter)											80.0	90.0	85.0	80.0	90.0
058	Mat or Panel Filter (Conventional)	NTE	058	058 (Mat or Panel Filter)											64.0	72.0	68.0	64.0	72.0
101	Mat or Panel Filter (High Efficiency, HEPA, ULPA)	TE	101	101 (High-Efficiency Particulate Air Filter (HEPA))											99.97	100.00	99.99	99.97	100.00
101	Mat or Panel Filter (High Efficiency, HEPA, ULPA)	NTE	101	101 (High-Efficiency Particulate Air Filter (HEPA))											79.98	80.00	79.99	79.98	80.00
057	Mechanically-Aided Scrubber	TE	057, 085	057 (Dynamic Separator (Wet)); 085 (Wet Cyclonic Separator)											70.0	99.0	84.5	70.0	99.0
057	Mechanically-Aided Scrubber	NTE	057, 085	057 (Dynamic Separator (Wet)); 085 (Wet Cyclonic Separator)											56.0	79.2	67.6	56.0	79.2
014	Mist Eliminator - Blade Type	TE	014, 015, 134, 151, 152	014 (Mist Eliminator - High Velocity, I.E. V>250 FT/MIN); 015 (Mist Eliminator - Low Velocity, I.E. V<250 FT/MIN); 134 (Demister); 151 (Fiber Mist Eliminator); 152 (Mist Eliminator - High Efficiency)											80.0	98.0	89.0	80.0	98.0
014	Mist Eliminator - Blade Type	NTE	014, 015, 134, 151, 152	014 (Mist Eliminator - High Velocity, I.E. V>250 FT/MIN); 015 (Mist Eliminator - Low Velocity, I.E. V<250 FT/MIN); 134 (Demister); 151 (Fiber Mist Eliminator); 152 (Mist Eliminator - High Efficiency)											64.0	78.4	71.2	64.0	78.4
015	Mist Eliminator - Mesh-Type	TE	014, 015, 134, 151, 152	014 (Mist Eliminator - High Velocity, I.E. V>250 FT/MIN); 015 (Mist Eliminator - Low Velocity, I.E. V<250 FT/MIN); 134 (Demister); 151 (Fiber Mist Eliminator); 152 (Mist Eliminator - High Efficiency)											95.0	99.0	97.0	95.0	99.0

MPCA			Applicable				GIT		Monitoring
Code	CONTROL DEVICE/METHOD	TE/NTE	EPA Codes	Device Description	Rep.	Low	High	Rep.	Parameter(s)
	PM Controls:								
519	Fabric Filter (Pulse-jet, Reverse-air, Mechanical Shaker) - Applied to Metal Fume Sources	TE	016, 017, 018, 100, 127	016 (Fabric Filter - High Velocity, I.E. T>250F); 017 (Fabric Filter - Medium Temperature, I.E. 180F<T<250F); 018 (Fabric Filter - Low Temperature, I.E. T<180F); 100 (Baghouse); 127 (Fabric Filter)	93.4				Gas stream **pressure drop**, flow rate, **opacity**, temperature, and dust removal
519	Fabric Filter (Pulse-jet, Reverse-air, Mechanical Shaker) - Applied to Metal Fume Sources	NTE	016, 017, 018, 100, 127	016 (Fabric Filter - High Velocity, I.E. T>250F); 017 (Fabric Filter - Medium Temperature, I.E. 180F<T<250F); 018 (Fabric Filter - Low Temperature, I.E. T<180F); 100 (Baghouse); 127 (Fabric Filter)	74.7				Gas stream **pressure drop**, flow rate, **opacity**, temperature, and dust removal
004	Gravity Collector (Expansion Chamber, Settling Chamber, Elutriators)	TE	004, 005, 006	004 (Gravity Collector - High Efficiency); 005 (Gravity Collector - Medium Efficiency); 006 (Gravity Collector - Low Efficiency)					**Gas stream velocity**
004	Gravity Collector (Expansion Chamber, Settling Chamber, Elutriators)	NTE	004, 005, 006	004 (Gravity Collector - High Efficiency); 005 (Gravity Collector - Medium Efficiency); 006 (Gravity Collector - Low Efficiency)					**Gas stream velocity**
058	Mat or Panel Filter (Conventional)	TE	058	058 (Mat or Panel Filter)	85.0				Condition of the filters, including, but not limited to, alignment, saturation, and tears and holes; **opacity**, temperature
058	Mat or Panel Filter (Conventional)	NTE	058	058 (Mat or Panel Filter)	68.0				Condition of the filters, including, but not limited to, alignment, saturation, and tears and holes; **opacity**, temperature
101	Mat or Panel Filter (High Efficiency, HEPA, ULPA)	TE	101	101 (High-Efficiency Particulate Air Filter (HEPA))	99.99				Condition of the filters, including, but not limited to, alignment, saturation, and tears and holes; **opacity**, temperature
101	Mat or Panel Filter (High Efficiency, HEPA, ULPA)	NTE	101	101 (High-Efficiency Particulate Air Filter (HEPA))	79.99				Condition of the filters, including, but not limited to, alignment, saturation, and tears and holes; **opacity**, temperature
057	Mechanically-Aided Scrubber	TE	057, 085	057 (Dynamic Separator (Wet)); 085 (Wet Cyclonic Separator)	84.5				**Pressure drop and water supply**
057	Mechanically-Aided Scrubber	NTE	057, 085	057 (Dynamic Separator (Wet)); 085 (Wet Cyclonic Separator)	67.6				**Pressure drop and water supply**
014	Mist Eliminator - Blade Type	TE	014, 015, 134, 151, 152	014 (Mist Eliminator - High Velocity, I.E. V>250 FT/MIN); 015 (Mist Eliminator - Low Velocity, I.E. V<250 FT/MIN); 134 (Demister); 151 (Fiber Mist Eliminator); 152 (Mist Eliminator - High Efficiency)	89.0				If not used as part of larger control system (e.g. on top of scrubber), **quarterly visual checks on blades and seals.**
014	Mist Eliminator - Blade Type	NTE	014, 015, 134, 151, 152	014 (Mist Eliminator - High Velocity, I.E. V>250 FT/MIN); 015 (Mist Eliminator - Low Velocity, I.E. V<250 FT/MIN); 134 (Demister); 151 (Fiber Mist Eliminator); 152 (Mist Eliminator - High Efficiency)	71.2				If not used as part of larger control system (e.g. on top of scrubber), **quarterly visual checks on blades and seals.**
015	Mist Eliminator - Mesh-Type	TE	014, 015, 134, 151, 152	014 (Mist Eliminator - High Velocity, I.E. V>250 FT/MIN); 015 (Mist Eliminator - Low Velocity, I.E. V<250 FT/MIN); 134 (Demister); 151 (Fiber Mist Eliminator); 152 (Mist Eliminator - High Efficiency)	97.0				If not used as part of larger control system (e.g. on top of scrubber), **quarterly visual checks for holes or tears.**

MPCA Code	CONTROL DEVICE/METHOD	TE/NTE	Applicable EPA Codes	Device Description	Record-keeping Requirements
	PM Controls:				
519	Fabric Filter (Pulse-jet, Reverse-air, Mechanical Shaker) - Applied to Metal Fume Sources	TE	016, 017, 018, 100, 127	016 (Fabric Filter - High Velocity, I.E. T>250F); 017 (Fabric Filter - Medium Temperature, I.E. 180F<T<250F); 018 (Fabric Filter - Low Temperature, I.E. T<180F); 100 (Baghouse); 127 (Fabric Filter)	Monthly/quarterly cleaning intensity and frequency, dust removal; daily records of gas stream pressure drop, flow rate, opacity, and temperature
519	Fabric Filter (Pulse-jet, Reverse-air, Mechanical Shaker) - Applied to Metal Fume Sources	NTE	016, 017, 018, 100, 127	016 (Fabric Filter - High Velocity, I.E. T>250F); 017 (Fabric Filter - Medium Temperature, I.E. 180F<T<250F); 018 (Fabric Filter - Low Temperature, I.E. T<180F); 100 (Baghouse); 127 (Fabric Filter)	Monthly/quarterly cleaning intensity and frequency, dust removal; daily records of gas stream pressure drop, flow rate, opacity, and temperature
004	Gravity Collector (Expansion Chamber, Settling Chamber, Elutriators)	TE	004, 005, 006	004 (Gravity Collector - High Efficiency); 005 (Gravity Collector - Medium Efficiency); 006 (Gravity Collector - Low Efficiency)	Record gas stream velocity every 24 hours
004	Gravity Collector (Expansion Chamber, Settling Chamber, Elutriators)	NTE	004, 005, 006	004 (Gravity Collector - High Efficiency); 005 (Gravity Collector - Medium Efficiency); 006 (Gravity Collector - Low Efficiency)	Record gas stream velocity every 24 hours
058	Mat or Panel Filter (Conventional)	TE	058	058 (Mat or Panel Filter)	Daily record of filter(s) condition; daily opacity and temperature.
058	Mat or Panel Filter (Conventional)	NTE	058	058 (Mat or Panel Filter)	Daily record of filter(s) condition; daily opacity and temperature.
101	Mat or Panel Filter (High Efficiency, HEPA, ULPA)	TE	101	101 (High-Efficiency Particulate Air Filter (HEPA))	Daily record of filter(s) condition; daily opacity and temperature.
101	Mat or Panel Filter (High Efficiency, HEPA, ULPA)	NTE	101	101 (High-Efficiency Particulate Air Filter (HEPA))	Daily record of filter(s) condition; daily opacity and temperature.
057	Mechanically-Aided Scrubber	TE	057, 085	057 (Dynamic Separator (Wet)); 085 (Wet Cyclonic Separator)	Recording of pressure drop and water supply rate
057	Mechanically-Aided Scrubber	NTE	057, 085	057 (Dynamic Separator (Wet)); 085 (Wet Cyclonic Separator)	Recording of pressure drop and water supply rate
014	Mist Eliminator - Blade Type	TE	014, 015, 134, 151, 152	014 (Mist Eliminator - High Velocity, I.E. V>250 FT/MIN); 015 (Mist Eliminator - Low Velocity, I.E. V<250 FT/MIN); 134 (Demister); 151 (Fiber Mist Eliminator); 152 (Mist Eliminator - High Efficiency)	Quarterly visual checks on blades and seals.
014	Mist Eliminator - Blade Type	NTE	014, 015, 134, 151, 152	014 (Mist Eliminator - High Velocity, I.E. V>250 FT/MIN); 015 (Mist Eliminator - Low Velocity, I.E. V<250 FT/MIN); 134 (Demister); 151 (Fiber Mist Eliminator); 152 (Mist Eliminator - High Efficiency)	Quarterly visual checks on blades and seals.
015	Mist Eliminator - Mesh-Type	TE	014, 015, 134, 151, 152	014 (Mist Eliminator - High Velocity, I.E. V>250 FT/MIN); 015 (Mist Eliminator - Low Velocity, I.E. V<250 FT/MIN); 134 (Demister); 151 (Fiber Mist Eliminator); 152 (Mist Eliminator - High Efficiency)	Quarterly visual checks for holes, tears, etc.

MPCA			Applicable		PM			PM10			PM2.5			SOx			NOx	
Code	CONTROL DEVICE/METHOD	TE/NTE	EPA Codes	Device Description	Low	High	Rep.	Low	High	Rep.	Low	High	Rep.	Low	High	Rep.	Low	High
	PM Controls:																	
015	Mist Eliminator - Mesh-Type	NTE	014, 015, 134, 151, 152	014 (Mist Eliminator - High Velocity, I.E. V>250 FT/MIN); 015 (Mist Eliminator - Low Velocity, I.E. V<250 FT/MIN); 134 (Demister); 151 (Fiber Mist Eliminator); 152 (Mist Eliminator - High Efficiency)	76.0	79.2	77.6	76.0	79.2	77.6	72.0	79.2	75.6					
502	Momentum Separator	TE	502	New Device	30.0	99.0	64.5	0.0	10.0	5.0	0.0	5.0	2.5					
502	Momentum Separator	NTE	502	New Device	24.0	79.2	51.6	0.0	8.0	4.0	0.0	4.0	2.0					
001	Packed-Bed Scrubber (Fiber-Bed, Moving-Bed, Cross-Flow, Grid-Packed)	TE	001, 002, 003, 117, 118, 129, 141, 155	001 (Wet Scrubber - High Efficiency); 002 (Wet Scrubber - Medium Efficiency); 003 (Wet Scrubber - Low Efficiency); 117 (Packed Scrubber); 118 (Crossflow Packed Bed); 129 (Scrubber); 141 (Wet Scrubber); 155 (Packed bed Scrubber - High Efficiency)	85.0	99.0	92.0	85.0	99.0	92.0	25.0	97.0	61.0					
001	Packed-Bed Scrubber (Fiber-Bed, Moving-Bed, Cross-Flow, Grid-Packed)	NTE	001, 002, 003, 117, 118, 129, 141, 155	001 (Wet Scrubber - High Efficiency); 002 (Wet Scrubber - Medium Efficiency); 003 (Wet Scrubber - Low Efficiency); 117 (Packed Scrubber); 118 (Crossflow Packed Bed); 129 (Scrubber); 141 (Wet Scrubber); 155 (Packed bed Scrubber - High Efficiency)	68.0	79.2	73.6	68.0	79.2	73.6	20.0	77.6	48.8					
504	Wet Rotoclone	TE	504	New Device		92.0	92.0											
504	Wet Rotoclone	NTE	504	New Device		73.6	73.6											
007	Single Cyclone - High Efficiency	TE	007, 075	075 (Single Cyclone)	80.0	99.0	89.5	60.0	95.0	77.5	20.0	70.0	45.0					
007	Single Cyclone - High Efficiency	NTE	007, 075	075 (Single Cyclone)	64.0	79.2	71.6	48.0	76.0	62.0	16.0	56.0	36.0					
008	Single Cyclone - Medium Efficiency (Conventional)	TE	008, 075	075 (Single Cyclone)	70.0	90.0	80.0	30.0	90.0	60.0	0.0	40.0	20.0					
008	Single Cyclone - Medium Efficiency (Conventional)	NTE	008, 075	075 (Single Cyclone)	56.0	72.0	64.0	24.0	72.0	48.0	0.0	32.0	16.0					
009	Single Cyclone - Low Efficiency (High Throughput)	TE	009, 075	075 (Single Cyclone)	80.0	99.0	89.5	10.0	40.0	25.0	0.0	10.0	5.0					
009	Single Cyclone - Low Efficiency (High Throughput)	NTE	009, 075	075 (Single Cyclone)	64.0	79.2	71.6	8.0	32.0	20.0	0.0	8.0	4.0					
076	Multiple Cyclone w/o Fly Ash Reinjection	TE	076	076 (Multiple Cyclone w/o Fly Ash Reinjection)	80.0	99.0	89.5	50.0	95.0	72.5	20.0	70.0	45.0					
076	Multiple Cyclone w/o Fly Ash Reinjection	NTE	076	076 (Multiple Cyclone w/o Fly Ash Reinjection)	64.0	79.2	71.6	40.0	76.0	58.0	16.0	56.0	36.0					
052	Spray Chamber Wet Scrubber (Spray Tower, Mist Scrubber, Cyclonic Spray Tower, Vane-type Cyclonic Tower)	TE	052, 123, 153	052 (Spray tower); 123 (Spray Scrubber); 153 (Water Sprays)	70.0	99.5	84.8	70.0	99.0	84.5	25.0	97.0	61.0	80.0	99.0	89.5		
052	Spray Chamber Wet Scrubber (Spray Tower, Mist Scrubber, Cyclonic Spray Tower, Vane-type Cyclonic Tower)	NTE	052, 123, 153	052 (Spray tower); 123 (Spray Scrubber); 153 (Water Sprays)	56.0	79.6	67.8	56.0	79.2	67.6	20.0	77.6	48.8	64.0	79.2	71.6		
055	Tray-Type Scrubber [Impingement Plate, Perforated Plate, Horizontal Impingement-Plate (Baffle)]	TE	055, 115	055 (Impingement Plate Scrubber); 115 (Impingement Type Wet Scrubber)	55.0	99.0	77.0	55.0	99.0	77.0	25.0	97.0	61.0	80.0	99.0	89.5		

MPCA			Applicable				CO			VOC			VOT			POT			PIT
Code	CONTROL DEVICE/METHOD	TE/NTE	EPA Codes	Device Description	Rep.	Low	High	Rep.	Low	High	Rep.	Low	High	Rep.	Low	High	Rep.	Low	High
	PM Controls:																		
015	Mist Eliminator - Mesh-Type	NTE	014, 015, 134, 151, 152	014 (Mist Eliminator - High Velocity, I.E. V>250 FT/MIN); 015 (Mist Eliminator - Low Velocity, I.E. V<250 FT/MIN); 134 (Demister); 151 (Fiber Mist Eliminator); 152 (Mist Eliminator - High Efficiency)											76.0	79.2	77.6	76.0	79.2
502	Momentum Separator	TE	502	New Device											0.0	10.0	5.0	0.0	10.0
502	Momentum Separator	NTE	502	New Device											0.0	8.0	4.0	0.0	8.0
001	Packed-Bed Scrubber (Fiber-Bed, Moving-Bed, Cross-Flow, Grid-Packed)	TE	001, 002, 003, 117, 118, 129, 141, 155	001 (Wet Scrubber - High Efficiency); 002 (Wet Scrubber - Medium Efficiency); 003 (Wet Scrubber - Low Efficiency); 117 (Packed Scrubber); 118 (Crossflow Packed Bed); 129 (Scrubber); 141 (Wet Scrubber); 155 (Packed bed Scrubber - High Efficiency)											85.0	99.0	92.0	85.0	99.0
001	Packed-Bed Scrubber (Fiber-Bed, Moving-Bed, Cross-Flow, Grid-Packed)	NTE	001, 002, 003, 117, 118, 129, 141, 155	001 (Wet Scrubber - High Efficiency); 002 (Wet Scrubber - Medium Efficiency); 003 (Wet Scrubber - Low Efficiency); 117 (Packed Scrubber); 118 (Crossflow Packed Bed); 129 (Scrubber); 141 (Wet Scrubber); 155 (Packed bed Scrubber - High Efficiency)											68.0	79.2	73.6	68.0	79.2
504	Wet Rotoclone	TE	504	New Device															
504	Wet Rotoclone	NTE	504	New Device															
007	Single Cyclone - High Efficiency	TE	007, 075	075 (Single Cyclone)											60.0	95.0	77.5	60.0	95.0
007	Single Cyclone - High Efficiency	NTE	007, 075	075 (Single Cyclone)											48.0	76.0	62.0	48.0	76.0
008	Single Cyclone - Medium Efficiency (Conventional)	TE	008, 075	075 (Single Cyclone)											30.0	90.0	60.0	30.0	90.0
008	Single Cyclone - Medium Efficiency (Conventional)	NTE	008, 075	075 (Single Cyclone)											24.0	72.0	48.0	24.0	72.0
009	Single Cyclone - Low Efficiency (High Throughput)	TE	009, 075	075 (Single Cyclone)											10.0	40.0	25.0	10.0	40.0
009	Single Cyclone - Low Efficiency (High Throughput)	NTE	009, 075	075 (Single Cyclone)											8.0	32.0	20.0	8.0	32.0
076	Multiple Cyclone w/o Fly Ash Reinjection	TE	076	076 (Multiple Cyclone w/o Fly Ash Reinjection)											50.0	95.0	72.5	50.0	95.0
076	Multiple Cyclone w/o Fly Ash Reinjection	NTE	076	076 (Multiple Cyclone w/o Fly Ash Reinjection)											40.0	76.0	58.0	40.0	76.0
052	Spray Chamber Wet Scrubber (Spray Tower, Mist Scrubber, Cyclonic Spray Tower, Vane-type Cyclonic Tower)	TE	052, 123, 153	052 (Spray tower); 123 (Spray Scrubber); 153 (Water Sprays)					50.0	95.0	72.5	50.0	95.0	72.5	70.0	99.0	84.5	70.0	99.0
052	Spray Chamber Wet Scrubber (Spray Tower, Mist Scrubber, Cyclonic Spray Tower, Vane-type Cyclonic Tower)	NTE	052, 123, 153	052 (Spray tower); 123 (Spray Scrubber); 153 (Water Sprays)					40.0	76.0	58.0	40.0	76.0	58.0	56.0	79.2	67.6	56.0	79.2
055	Tray-Type Scrubber [Impingement Plate, Perforated Plate, Horizontal Impingement-Plate (Baffle)]	TE	055, 115	055 (Impingement Plate Scrubber); 115 (Impingement Type Wet Scrubber)											55.0	99.0	85.0	55.0	99.0

MPCA Code	CONTROL DEVICE/METHOD	TE/NTE	Applicable EPA Codes	Device Description	Rep.	GIT Low	GIT High	GIT Rep.	Monitoring Parameter(s)
	PM Controls:								
015	Mist Eliminator - Mesh-Type	NTE	014, 015, 134, 151, 152	014 (Mist Eliminator - High Velocity, I.E. V>250 FT/MIN); 015 (Mist Eliminator - Low Velocity, I.E. V<250 FT/MIN); 134 (Demister); 151 (Fiber Mist Eliminator); 152 (Mist Eliminator - High Efficiency)	77.6				If not used as part of larger control system (e.g. on top of scrubber), **quarterly visual checks for holes or tears.**
502	Momentum Separator	TE	502	New Device	5.0				**Gas stream velocity and pressure drop**
502	Momentum Separator	NTE	502	New Device	4.0				**Gas stream velocity and pressure drop**
001	Packed-Bed Scrubber (Fiber-Bed, Moving-Bed, Cross-Flow, Grid-Packed)	TE	001, 002, 003, 117, 118, 129, 141, 155	001 (Wet Scrubber - High Efficiency); 002 (Wet Scrubber - Medium Efficiency); 003 (Wet Scrubber - Low Efficiency); 117 (Packed Scrubber); 118 (Crossflow Packed Bed); 129 (Scrubber); 141 (Wet Scrubber); 155 (Packed bed Scrubber - High Efficiency)	92.0				**Liquid flow rate and flue gas pressure drop**
001	Packed-Bed Scrubber (Fiber-Bed, Moving-Bed, Cross-Flow, Grid-Packed)	NTE	001, 002, 003, 117, 118, 129, 141, 155	001 (Wet Scrubber - High Efficiency); 002 (Wet Scrubber - Medium Efficiency); 003 (Wet Scrubber - Low Efficiency); 117 (Packed Scrubber); 118 (Crossflow Packed Bed); 129 (Scrubber); 141 (Wet Scrubber); 155 (Packed bed Scrubber - High Efficiency)	73.6				**Liquid flow rate and flue gas pressure drop**
504	Wet Rotoclone	TE	504	New Device					**Supply water depth, pressure drop,** and flue gas flow rate
504	Wet Rotoclone	NTE	504	New Device					**Supply water depth, pressure drop,** and flue gas flow rate
007	Single Cyclone - High Efficiency	TE	007, 075	075 (Single Cyclone)	77.5				**Pressure drop**
007	Single Cyclone - High Efficiency	NTE	007, 075	075 (Single Cyclone)	62.0				**Pressure drop**
008	Single Cyclone - Medium Efficiency (Conventional)	TE	008, 075	075 (Single Cyclone)	60.0				**Pressure drop**
008	Single Cyclone - Medium Efficiency (Conventional)	NTE	008, 075	075 (Single Cyclone)	48.0				**Pressure drop**
009	Single Cyclone - Low Efficiency (High Throughput)	TE	009, 075	075 (Single Cyclone)	25.0				**Pressure drop**
009	Single Cyclone - Low Efficiency (High Throughput)	NTE	009, 075	075 (Single Cyclone)	20.0				**Pressure drop**
076	Multiple Cyclone w/o Fly Ash Reinjection	TE	076	076 (Multiple Cyclone w/o Fly Ash Reinjection)	72.5				**Pressure drop**
076	Multiple Cyclone w/o Fly Ash Reinjection	NTE	076	076 (Multiple Cyclone w/o Fly Ash Reinjection)	58.0				**Pressure drop**
052	Spray Chamber Wet Scrubber (Spray Tower, Mist Scrubber, Cyclonic Spray Tower, Vane-type Cyclonic Tower)	TE	052, 123, 153	052 (Spray tower); 123 (Spray Scrubber); 153 (Water Sprays)	84.5	85.0	99.0	92.0	Depending on the application, can be one or more of the following: **Liquid flow rate, flue gas pressure drop** and temperature, concentration of reacting solution or slurry if used, pH of absorbing solution.
052	Spray Chamber Wet Scrubber (Spray Tower, Mist Scrubber, Cyclonic Spray Tower, Vane-type Cyclonic Tower)	NTE	052, 123, 153	052 (Spray tower); 123 (Spray Scrubber); 153 (Water Sprays)	67.6	68.0	79.2	73.6	Depending on the application, can be one or more of the following: **Liquid flow rate, flue gas pressure drop** and temperature, concentration of reacting solution or slurry if used, pH of absorbing solution.
055	Tray-Type Scrubber [Impingement Plate, Perforated Plate, Horizontal Impingement-Plate (Baffle)]	TE	055, 115	055 (Impingement Plate Scrubber); 115 (Impingement Type Wet Scrubber)	85.0				Depending on the application, can be one or more of the following: **Liquid flow rate, flue gas pressure drop** and temperature, concentration of reacting solution or slurry if used, pH of absorbing solution.

MPCA Code	CONTROL DEVICE/METHOD	TE/NTE	Applicable EPA Codes	Device Description	Record-keeping Requirements
	PM Controls:				
015	Mist Eliminator - Mesh-Type	NTE	014, 015, 134, 151, 152	014 (Mist Eliminator - High Velocity, I.E. V>250 FT/MIN); 015 (Mist Eliminator - Low Velocity, I.E. V<250 FT/MIN); 134 (Demister); 151 (Fiber Mist Eliminator); 152 (Mist Eliminator - High Efficiency)	Quarterly visual checks for holes, tears, etc.
502	Momentum Separator	TE	502	New Device	Recording of gas stream velocity and pressure drop
502	Momentum Separator	NTE	502	New Device	Recording of gas stream velocity and pressure drop
001	Packed-Bed Scrubber (Fiber-Bed, Moving-Bed, Cross-Flow, Grid-Packed)	TE	001, 002, 003, 117, 118, 129, 141, 155	001 (Wet Scrubber - High Efficiency); 002 (Wet Scrubber - Medium Efficiency); 003 (Wet Scrubber - Low Efficiency); 117 (Packed Scrubber); 118 (Crossflow Packed Bed); 129 (Scrubber); 141 (Wet Scrubber); 155 (Packed bed Scrubber - High Efficiency)	Recording of liquid flow rate and pressure drop every 24 hours
001	Packed-Bed Scrubber (Fiber-Bed, Moving-Bed, Cross-Flow, Grid-Packed)	NTE	001, 002, 003, 117, 118, 129, 141, 155	001 (Wet Scrubber - High Efficiency); 002 (Wet Scrubber - Medium Efficiency); 003 (Wet Scrubber - Low Efficiency); 117 (Packed Scrubber); 118 (Crossflow Packed Bed); 129 (Scrubber); 141 (Wet Scrubber); 155 (Packed bed Scrubber - High Efficiency)	Recording of liquid flow rate and pressure drop every 24 hours
504	Wet Rotoclone	TE	504	New Device	Recording of water level, flue gas flow rate and pressure drop every 24 hours
504	Wet Rotoclone	NTE	504	New Device	Recording of water level, flue gas flow rate and pressure drop every 24 hours
007	Single Cyclone - High Efficiency	TE	007, 075	075 (Single Cyclone)	Record pressure drop every 24 hours
007	Single Cyclone - High Efficiency	NTE	007, 075	075 (Single Cyclone)	Record pressure drop every 24 hours
008	Single Cyclone - Medium Efficiency (Conventional)	TE	008, 075	075 (Single Cyclone)	Record pressure drop every 24 hours
008	Single Cyclone - Medium Efficiency (Conventional)	NTE	008, 075	075 (Single Cyclone)	Record pressure drop every 24 hours
009	Single Cyclone - Low Efficiency (High Throughput)	TE	009, 075	075 (Single Cyclone)	Record pressure drop every 24 hours
009	Single Cyclone - Low Efficiency (High Throughput)	NTE	009, 075	075 (Single Cyclone)	Record pressure drop every 24 hours
076	Multiple Cyclone w/o Fly Ash Reinjection	TE	076	076 (Multiple Cyclone w/o Fly Ash Reinjection)	Record pressure drop every 24 hours
076	Multiple Cyclone w/o Fly Ash Reinjection	NTE	076	076 (Multiple Cyclone w/o Fly Ash Reinjection)	Record pressure drop every 24 hours
052	Spray Chamber Wet Scrubber (Spray Tower, Mist Scrubber, Cyclonic Spray Tower, Vane-type Cyclonic Tower)	TE	052, 123, 153	052 (Spray tower); 123 (Spray Scrubber); 153 (Water Sprays)	Depending on the application, one or more of the following: Daily records of liquid flow rate, flue gas pressure drop and temperature, reacting solution or slurry if used, pH, reagent usage.
052	Spray Chamber Wet Scrubber (Spray Tower, Mist Scrubber, Cyclonic Spray Tower, Vane-type Cyclonic Tower)	NTE	052, 123, 153	052 (Spray tower); 123 (Spray Scrubber); 153 (Water Sprays)	Depending on the application, one or more of the following: Daily records of liquid flow rate, flue gas pressure drop and temperature, reacting solution or slurry if used, pH, reagent usage.
055	Tray-Type Scrubber [Impingement Plate, Perforated Plate, Horizontal Impingement-Plate (Baffle)]	TE	055, 115	055 (Impingement Plate Scrubber); 115 (Impingement Type Wet Scrubber)	Depending on the application, one or more of the following: Daily records of liquid flow rate, flue gas pressure drop and temperature, reacting solution or slurry if used, pH, reagent usage.

MPCA			Applicable		PM			PM10			PM2.5			SOx			NOx	
Code	CONTROL DEVICE/METHOD	TE/NTE	EPA Codes	Device Description	Low	High	Rep.	Low	High	Rep.	Low	High	Rep.	Low	High	Rep.	Low	High
	PM Controls:																	
055	Tray-Type Scrubber [Impingement Plate, Perforated Plate, Horizontal Impingement-Plate (Baffle)]	NTE	055, 115	055 (Impingement Plate Scrubber); 115 (Impingement Type Wet Scrubber)	44.0	79.2	61.6	44.0	79.2	61.6	20.0	77.6	48.8	64.0	79.2	71.6		
053	Venturi or Orifice Scrubber	TE	053	053 (Venturi Scrubber)	90.0	99.0	94.5	70.0	99.0	84.5	25.0	99.0	62.0	80.0	99.0	89.5		
053	Venturi or Orifice Scrubber	NTE	053	053 (Venturi Scrubber)	72.0	79.2	75.6	56.0	79.2	67.6	20.0	79.2	49.6	64.0	79.2	71.6		
086	Water Curtain	TE	086	086 (Water Curtain)	10.0	95.0	52.5											
086	Water Curtain	NTE	086	086 (Water Curtain)	8.0	76.0	42.0											
141	Wet Scrubber (General, Not Classified)	TE	001, 002, 003, 117, 118, 129, 141, 155	001 (Wet Scrubber - High Efficiency); 002 (Wet Scrubber - Medium Efficiency); 003 (Wet Scrubber - Low Efficiency); 117 (Packed Scrubber); 118 (Crossflow Packed Bed); 129 (Scrubber); 141 (Wet Scrubber); 155 (Packed bed Scrubber - High Efficiency)	55.0	99.9	77.5	55.0	99.9	77.5	25.0	97.0	61.0	80.0	99.0	90.0		
141	Wet Scrubber (General, Not Classified)	NTE	001, 002, 003, 117, 118, 129, 141, 155	001 (Wet Scrubber - High Efficiency); 002 (Wet Scrubber - Medium Efficiency); 003 (Wet Scrubber - Low Efficiency); 117 (Packed Scrubber); 118 (Crossflow Packed Bed); 129 (Scrubber); 141 (Wet Scrubber); 155 (Packed bed Scrubber - High Efficiency)	44.0	79.9	62.0	44.0	79.9	62.0	20.0	77.6	48.8	64.0	79.2	72.0		
063	Gravel Bed Filter	TE	063	063 (Gravel Bed Filter)	90.0	99.5	94.8	85.0	99.0	92.0	80.0	99.0	89.5					
063	Gravel Bed Filter	NTE	063	063 (Gravel Bed Filter)	72.0	79.6	75.8	68.0	79.2	73.6	64.0	79.2	71.6					
520	Gravel Bed Moving Filter	TE	520	New Device	80.0	95.0	87.5	70.0	90.0	80.0								
520	Gravel Bed Moving Filter	NTE	520	New Device	64.0	76.0	70.0	56.0	72.0	64.0								
505	Gravel Bed Moving Filter - Electrostatically Augmented	TE	505	New Device	80.0	99.0	89.5	70.0	95.0	82.5								
505	Gravel Bed Moving Filter - Electrostatically Augmented	NTE	505	New Device	64.0	79.2	71.6	56.0	76.0	66.0								
071	Fluidized Bed Dry Scrubber	TE	071, 098, 119, 120	071 (Fluid Bed Dry Scrubber); 098 (Moving Bed Dry Scrubber); 119 (Dry Scrubber); 120 (Floating Bed Scrubber)	90.0	99.9	95.0	85.0	99.9	92.5	80.0	99.9	90.0					
071	Fluidized Bed Dry Scrubber	NTE	071, 098, 119, 120	071 (Fluid Bed Dry Scrubber); 098 (Moving Bed Dry Scrubber); 119 (Dry Scrubber); 120 (Floating Bed Scrubber)	72.0	79.9	76.0	68.0	79.9	74.0	64.0	79.9	72.0					
	VOC Controls:																	
048	Adsorption: various adsorbents, including activated carbon, zeolites, molecular sieves, silicates, aluminas, synthetic resins, and lime	TE	048, 084	048 (Activated Carbon Adsorption); 084 (Activated Clay Adsorption)										70.0	80.0	75.0		

MPCA			Applicable		CO			VOC			VOT			POT			PIT		
Code	CONTROL DEVICE/METHOD	TE/NTE	EPA Codes	Device Description	Rep.	Low	High	Rep.	Low	High	Rep.	Low	High	Rep.	Low	High	Rep.	Low	High
	PM Controls:																		
055	Tray-Type Scrubber [Impingement Plate, Perforated Plate, Horizontal Impingement-Plate (Baffle)]	NTE	055, 115	055 (Impingement Plate Scrubber); 115 (Impingement Type Wet Scrubber)											44.0	79.2	68.0	44.0	79.2
053	Venturi or Orifice Scrubber	TE	053	053 (Venturi Scrubber)											70.0	99.0	85.0	70.0	99.0
053	Venturi or Orifice Scrubber	NTE	053	053 (Venturi Scrubber)											56.0	79.2	68.0	56.0	79.2
086	Water Curtain	TE	086	086 (Water Curtain)															
086	Water Curtain	NTE	086	086 (Water Curtain)															
141	Wet Scrubber (General, Not Classified)	TE	001, 002, 003, 117, 118, 129, 141, 155	001 (Wet Scrubber - High Efficiency); 002 (Wet Scrubber - Medium Efficiency); 003 (Wet Scrubber - Low Efficiency); 117 (Packed Scrubber); 118 (Crossflow Packed Bed); 129 (Scrubber); 141 (Wet Scrubber); 155 (Packed bed Scrubber - High Efficiency)					50.0	95.0	90.0	50.0	95.0	85.0	55.0	99.9	85.0	55.0	99.9
141	Wet Scrubber (General, Not Classified)	NTE	001, 002, 003, 117, 118, 129, 141, 155	001 (Wet Scrubber - High Efficiency); 002 (Wet Scrubber - Medium Efficiency); 003 (Wet Scrubber - Low Efficiency); 117 (Packed Scrubber); 118 (Crossflow Packed Bed); 129 (Scrubber); 141 (Wet Scrubber); 155 (Packed bed Scrubber - High Efficiency)					40.0	76.0	72.0	40.0	76.0	68.0	44.0	79.9	68.0	44.0	79.9
063	Gravel Bed Filter	TE	063	063 (Gravel Bed Filter)											85.0	99.0	85.0	85.0	99.0
063	Gravel Bed Filter	NTE	063	063 (Gravel Bed Filter)											68.0	79.2	68.0	68.0	79.2
520	Gravel Bed Moving Filter	TE	520	New Device											70.0	90.0	85.0	70.0	90.0
520	Gravel Bed Moving Filter	NTE	520	New Device											56.0	72.0	68.0	56.0	72.0
505	Gravel Bed Moving Filter - Electrostatically Augmented	TE	505	New Device											70.0	95.0	85.0	70.0	95.0
505	Gravel Bed Moving Filter - Electrostatically Augmented	NTE	505	New Device											56.0	76.0	68.0	56.0	76.0
071	Fluidized Bed Dry Scrubber	TE	071, 098, 119, 120	071 (Fluid Bed Dry Scrubber); 098 (Moving Bed Dry Scrubber); 119 (Dry Scrubber); 120 (Floating Bed Scrubber)					80.0	90.0	85.0	80.0	90.0	85.0	85.0	99.9	85.0	85.0	99.9
071	Fluidized Bed Dry Scrubber	NTE	071, 098, 119, 120	071 (Fluid Bed Dry Scrubber); 098 (Moving Bed Dry Scrubber); 119 (Dry Scrubber); 120 (Floating Bed Scrubber)					64.0	72.0	68.0	64.0	72.0	68.0	68.0	79.9	68.0	68.0	79.9
	VOC Controls:																		
048	Adsorption: various adsorbents, including activated carbon, zeolites, molecular sieves, silicates, aluminas, synthetic resins, and lime	TE	048, 084	048 (Activated Carbon Adsorption); 084 (Activated Clay Adsorption)					90.0	99.0	94.5	90.0	99.0	94.5					

MPCA Code	CONTROL DEVICE/METHOD	TE/NTE	Applicable EPA Codes	Device Description	Rep.	Low	GIT High	Rep.	Monitoring Parameter(s)
	PM Controls:								
055	Tray-Type Scrubber [Impingement Plate, Perforated Plate, Horizontal Impingement-Plate (Baffle)]	NTE	055, 115	055 (Impingement Plate Scrubber); 115 (Impingement Type Wet Scrubber)	68.0				Depending on the application, can be one or more of the following: **Liquid flow rate, flue gas pressure drop** and temperature, concentration of reacting solution or slurry if used, pH of absorbing solution.
053	Venturi or Orifice Scrubber	TE	053	053 (Venturi Scrubber)	85.0				**Liquid flow rate, flue gas pressure drop** and temperature
053	Venturi or Orifice Scrubber	NTE	053	053 (Venturi Scrubber)	68.0				**Liquid flow rate, flue gas pressure drop** and temperature
086	Water Curtain	TE	086	086 (Water Curtain)					**Water flow rate**, flue gas pressure drop and temperature
086	Water Curtain	NTE	086	086 (Water Curtain)					**Water flow rate**, flue gas pressure drop and temperature
141	Wet Scrubber (General, Not Classified)	TE	001, 002, 003, 117, 118, 129, 141, 155	001 (Wet Scrubber - High Efficiency); 002 (Wet Scrubber - Medium Efficiency); 003 (Wet Scrubber - Low Efficiency); 117 (Packed Scrubber); 118 (Crossflow Packed Bed); 129 (Scrubber); 141 (Wet Scrubber); 155 (Packed bed Scrubber - High Efficiency)	85.0				Depending on the application, can be one or more of the following: **Liquid flow rate, flue gas pressure drop** and temperature, concentration of reacting solution or slurry if used, pH of absorbing solution.
141	Wet Scrubber (General, Not Classified)	NTE	001, 002, 003, 117, 118, 129, 141, 155	001 (Wet Scrubber - High Efficiency); 002 (Wet Scrubber - Medium Efficiency); 003 (Wet Scrubber - Low Efficiency); 117 (Packed Scrubber); 118 (Crossflow Packed Bed); 129 (Scrubber); 141 (Wet Scrubber); 155 (Packed bed Scrubber - High Efficiency)	68.0				Depending on the application, can be one or more of the following: **Liquid flow rate, flue gas pressure drop** and temperature, concentration of reacting solution or slurry if used, pH of absorbing solution.
063	Gravel Bed Filter	TE	063	063 (Gravel Bed Filter)	85.0				**Pressure drop**
063	Gravel Bed Filter	NTE	063	063 (Gravel Bed Filter)	68.0				**Pressure drop**
520	Gravel Bed Moving Filter	TE	520	New Device	85.0				**Pressure drop**
520	Gravel Bed Moving Filter	NTE	520	New Device	68.0				**Pressure drop**
505	Gravel Bed Moving Filter - Electrostatically Augmented	TE	505	New Device	85.0				**Pressure drop**, voltage, current
505	Gravel Bed Moving Filter - Electrostatically Augmented	NTE	505	New Device	68.0				**Pressure drop**, voltage, current
071	Fluidized Bed Dry Scrubber	TE	071, 098, 119, 120	071 (Fluid Bed Dry Scrubber); 098 (Moving Bed Dry Scrubber); 119 (Dry Scrubber); 120 (Floating Bed Scrubber)	85.0				**Pressure drop**
071	Fluidized Bed Dry Scrubber	NTE	071, 098, 119, 120	071 (Fluid Bed Dry Scrubber); 098 (Moving Bed Dry Scrubber); 119 (Dry Scrubber); 120 (Floating Bed Scrubber)	68.0				**Pressure drop**
	VOC Controls:								
048	Adsorption: various adsorbents, including activated carbon, zeolites, molecular sieves, silicates, aluminas, synthetic resins, and lime	TE	048, 084	048 (Activated Carbon Adsorption); 084 (Activated Clay Adsorption)		90.0	99.0	94.5	Flue gas humidity, temperature, pressure drop, **inlet and outlet pollutant concentrations.**

MPCA Code	CONTROL DEVICE/METHOD	TE/NTE	Applicable EPA Codes	Device Description	Record-keeping Requirements
	PM Controls:				
055	Tray-Type Scrubber [Impingement Plate, Perforated Plate, Horizontal Impingement-Plate (Baffle)]	NTE	055, 115	055 (Impingement Plate Scrubber); 115 (Impingement Type Wet Scrubber)	Depending on the application, one or more of the following: Daily records of liquid flow rate, flue gas pressure drop and temperature, reacting solution or slurry if used, pH, reagent usage.
053	Venturi or Orifice Scrubber	TE	053	053 (Venturi Scrubber)	Daily records of liquid flow rate, flue gas pressure drop and temperature.
053	Venturi or Orifice Scrubber	NTE	053	053 (Venturi Scrubber)	Daily records of liquid flow rate, flue gas pressure drop and temperature.
086	Water Curtain	TE	086	086 (Water Curtain)	Daily records of water flow rate, flue gas pressure drop and temperature
086	Water Curtain	NTE	086	086 (Water Curtain)	Daily records of water flow rate, flue gas pressure drop and temperature
141	Wet Scrubber (General, Not Classified)	TE	001, 002, 003, 117, 118, 129, 141, 155	001 (Wet Scrubber - High Efficiency); 002 (Wet Scrubber - Medium Efficiency); 003 (Wet Scrubber - Low Efficiency); 117 (Packed Scrubber); 118 (Crossflow Packed Bed); 129 (Scrubber); 141 (Wet Scrubber); 155 (Packed bed Scrubber - High Efficiency)	Depending on the application, one or more of the following: Daily records of liquid flow rate, flue gas pressure drop and temperature, reacting solution or slurry if used, pH, reagent usage.
141	Wet Scrubber (General, Not Classified)	NTE	001, 002, 003, 117, 118, 129, 141, 155	001 (Wet Scrubber - High Efficiency); 002 (Wet Scrubber - Medium Efficiency); 003 (Wet Scrubber - Low Efficiency); 117 (Packed Scrubber); 118 (Crossflow Packed Bed); 129 (Scrubber); 141 (Wet Scrubber); 155 (Packed bed Scrubber - High Efficiency)	Depending on the application, one or more of the following: Daily records of liquid flow rate, flue gas pressure drop and temperature, reacting solution or slurry if used, pH, reagent usage.
063	Gravel Bed Filter	TE	063	063 (Gravel Bed Filter)	Record pressure drop every 24 hours
063	Gravel Bed Filter	NTE	063	063 (Gravel Bed Filter)	Record pressure drop every 24 hours
520	Gravel Bed Moving Filter	TE	520	New Device	Record pressure drop every 24 hours
520	Gravel Bed Moving Filter	NTE	520	New Device	Record pressure drop every 24 hours
505	Gravel Bed Moving Filter - Electrostatically Augmented	TE	505	New Device	Record pressure drop, voltage, and current every 24 hours
505	Gravel Bed Moving Filter - Electrostatically Augmented	NTE	505	New Device	Record pressure drop, voltage, and current every 24 hours
071	Fluidized Bed Dry Scrubber	TE	071, 098, 119, 120	071 (Fluid Bed Dry Scrubber); 098 (Moving Bed Dry Scrubber); 119 (Dry Scrubber); 120 (Floating Bed Scrubber)	Record pressure drop every 24 hours
071	Fluidized Bed Dry Scrubber	NTE	071, 098, 119, 120	071 (Fluid Bed Dry Scrubber); 098 (Moving Bed Dry Scrubber); 119 (Dry Scrubber); 120 (Floating Bed Scrubber)	Record pressure drop every 24 hours
	VOC Controls:				
048	Adsorption: various adsorbents, including activated carbon, zeolites, molecular sieves, silicates, aluminas, synthetic resins, and lime	TE	048, 084	048 (Activated Carbon Adsorption); 084 (Activated Clay Adsorption)	Daily readings of flue gas humidity, temperature, pressure drop; continuous or vendor-specified monitoring of inlet and outlet VOC concentrations; recording of carbon replacement or regeneration frequency.

MPCA Code	CONTROL DEVICE/METHOD	TE/NTE	Applicable EPA Codes	Device Description	PM			PM10			PM2.5			SOx			NOx	
					Low	High	Rep.	Low	High	Rep.	Low	High	Rep.	Low	High	Rep.	Low	High
	PM Controls:																	
048	Adsorption: various adsorbents, including activated carbon, zeolites, molecular sieves, silicates, aluminas, synthetic resins, and lime	NTE	048, 084	048 (Activated Carbon Adsorption); 084 (Activated Clay Adsorption)										56.0	64.0	60.0		
506	Biofiltration	TE	506	New Device													75.0	90.0
506	Biofiltration	NTE	506	New Device													60.0	72.0
109	Catalytic Oxidizer (Catalytic Incinerator)	TE	019, 020, 109, 116	019 (Catalytic Afterburner); 020 (Catalytic Afterburner with Heat Exchanger); 109 (Catalytic Oxidizer); 116 (Catalytic Incinerator)	25.0	99.0	62.0	25.0	99.9	62.5								
109	Catalytic Oxidizer (Catalytic Incinerator)	NTE	019, 020, 109, 116	019 (Catalytic Afterburner); 020 (Catalytic Afterburner with Heat Exchanger); 109 (Catalytic Oxidizer); 116 (Catalytic Incinerator)	20.0	79.2	49.6	20.0	79.9	50.0								
074	Contact Condenser (Barometric Condenser)	TE	074, 132	074 (Barometric Condenser); 132 (Condenser)														
074	Contact Condenser (Barometric Condenser)	NTE	074, 132	074 (Barometric Condenser); 132 (Condenser)														
021	Direct Flame Thermal Oxidizer (Thermal Incinerator)	TE	021, 022, 131, 133	021 (Direct Flame Afterburner); 022 (Direct Flame Afterburner with Heat Exchanger); 131 (Thermal Oxidizer); 133 (Incinerator)	25.0	99.0	62.0	25.0	99.0	62.0								
021	Direct Flame Thermal Oxidizer (Thermal Incinerator)	NTE	021, 022, 131, 133	021 (Direct Flame Afterburner); 022 (Direct Flame Afterburner with Heat Exchanger); 131 (Thermal Oxidizer); 133 (Incinerator)	20.0	79.2	49.6	20.0	79.2	49.6								
023	Flaring	TE	023	023 (Flaring)	25.0	98.0	61.5	25.0	98.0	61.5								
023	Flaring	NTE	023	023 (Flaring)	20.0	78.4	49.2	20.0	78.4	49.2								
050	Packed Column - Gas Absorption	TE	050	050 (Packed-Gas Absorption Column)										80.0	99.0	89.5		
050	Packed Column - Gas Absorption	NTE	050	050 (Packed-Gas Absorption Column)										64.0	79.2	71.6		
073	Refrigerated Condenser	TE	073, 132	073 (Refrigerated Condenser); 132 (Condenser)														
073	Refrigerated Condenser	NTE	073, 132	073 (Refrigerated Condenser); 132 (Condenser)														

MPCA			Applicable				CO			VOC			VOT			POT			PIT
Code	CONTROL DEVICE/METHOD	TE/NTE	EPA Codes	Device Description	Rep.	Low	High	Rep.	Low	High	Rep.	Low	High	Rep.	Low	High	Rep.	Low	High
	PM Controls:																		
048	Adsorption: various adsorbents, including activated carbon, zeolites, molecular sieves, silicates, aluminas, synthetic resins, and lime	NTE	048, 084	048 (Activated Carbon Adsorption); 084 (Activated Clay Adsorption)					72.0	79.2	75.6	72.0	79.2	75.6					
506	Biofiltration	TE	506	New Device	82.5				75.0	99.0	87.0	75.0	99.0	87.0					
506	Biofiltration	NTE	506	New Device	66.0				60.0	79.2	69.6	60.0	79.2	69.6					
109	Catalytic Oxidizer (Catalytic Incinerator)	TE	019, 020, 109, 116	019 (Catalytic Afterburner); 020 (Catalytic Afterburner with Heat Exchanger); 109 (Catalytic Oxidizer); 116 (Catalytic Incinerator)		90.0	99.0	94.5	90.0	99.0	94.5	90.0	99.0	94.5	90.0	99.0	94.5		
109	Catalytic Oxidizer (Catalytic Incinerator)	NTE	019, 020, 109, 116	019 (Catalytic Afterburner); 020 (Catalytic Afterburner with Heat Exchanger); 109 (Catalytic Oxidizer); 116 (Catalytic Incinerator)		72.0	79.2	75.6	72.0	79.2	75.6	72.0	79.2	75.6	72.0	79.2	75.6		
074	Contact Condenser (Barometric Condenser)	TE	074, 132	074 (Barometric Condenser); 132 (Condenser)					50.0	90.0	70.0	50.0	90.0	70.0					
074	Contact Condenser (Barometric Condenser)	NTE	074, 132	074 (Barometric Condenser); 132 (Condenser)					40.0	72.0	56.0	40.0	72.0	56.0					
021	Direct Flame Thermal Oxidizer (Thermal Incinerator)	TE	021, 022, 131, 133	021 (Direct Flame Afterburner); 022 (Direct Flame Afterburner with Heat Exchanger); 131 (Thermal Oxidizer); 133 (Incinerator)		95.0	99.0	97.0	95.0	99.0	97.0	95.0	99.0	97.0	95.0	99.0	97.0		
021	Direct Flame Thermal Oxidizer (Thermal Incinerator)	NTE	021, 022, 131, 133	021 (Direct Flame Afterburner); 022 (Direct Flame Afterburner with Heat Exchanger); 131 (Thermal Oxidizer); 133 (Incinerator)		76.0	79.2	77.6	76.0	79.2	77.6	76.0	79.2	77.6	76.0	79.2	77.6		
023	Flaring	TE	023	023 (Flaring)		98.0	99.0	98.5	98.0	99.0	98.5	98.0	99.0	98.5	98.0	99.0	98.5		
023	Flaring	NTE	023	023 (Flaring)		78.4	79.2	78.8	78.4	79.2	78.8	78.4	79.2	78.8	78.4	79.2	78.8		
050	Packed Column - Gas Absorption	TE	050	050 (Packed-Gas Absorption Column)					70.0	99.0	84.5	70.0	99.0	84.5					
050	Packed Column - Gas Absorption	NTE	050	050 (Packed-Gas Absorption Column)					56.0	79.2	67.6	56.0	79.2	67.6					
073	Refrigerated Condenser	TE	073, 132	073 (Refrigerated Condenser); 132 (Condenser)					50.0	95.0	72.5	50.0	95.0	72.5					
073	Refrigerated Condenser	NTE	073, 132	073 (Refrigerated Condenser); 132 (Condenser)					40.0	76.0	58.0	40.0	76.0	58.0					

MPCA			Applicable				GIT		Monitoring
Code	CONTROL DEVICE/METHOD	TE/NTE	EPA Codes	Device Description	Rep.	Low	High	Rep.	Parameter(s)
	PM Controls:								
048	Adsorption: various adsorbents, including activated carbon, zeolites, molecular sieves, silicates, aluminas, synthetic resins, and lime	NTE	048, 084	048 (Activated Carbon Adsorption); 084 (Activated Clay Adsorption)		72.0	79.2	75.6	Flue gas humidity, temperature, pressure drop, **inlet and outlet pollutant concentrations.**
506	Biofiltration	TE	506	New Device					**Bed temperature, moisture**, nutrients (Nitrogen, phosphorus, potassium), pH, and inlet VOC concentration
506	Biofiltration	NTE	506	New Device					**Bed temperature, moisture**, nutrients (Nitrogen, phosphorus, potassium), pH, and inlet VOC concentration
109	Catalytic Oxidizer (Catalytic Incinerator)	TE	019, 020, 109, 116	019 (Catalytic Afterburner); 020 (Catalytic Afterburner with Heat Exchanger); 109 (Catalytic Oxidizer); 116 (Catalytic Incinerator)					**Combustion zone temperature**, PM and **oxygen** concentrations, flue gas flow rate, auxiliary fuel supply rate, and other specifications required by the equipment vendor.
109	Catalytic Oxidizer (Catalytic Incinerator)	NTE	019, 020, 109, 116	019 (Catalytic Afterburner); 020 (Catalytic Afterburner with Heat Exchanger); 109 (Catalytic Oxidizer); 116 (Catalytic Incinerator)					**Combustion zone temperature**, PM and **oxygen** concentrations, flue gas flow rate, auxiliary fuel supply rate, and other specifications required by the equipment vendor.
074	Contact Condenser (Barometric Condenser)	TE	074, 132	074 (Barometric Condenser); 132 (Condenser)					**Water flow rate and temperature, flue gas temperature**
074	Contact Condenser (Barometric Condenser)	NTE	074, 132	074 (Barometric Condenser); 132 (Condenser)					**Water flow rate and temperature, flue gas temperature**
021	Direct Flame Thermal Oxidizer (Thermal Incinerator)	TE	021, 022, 131, 133	021 (Direct Flame Afterburner); 022 (Direct Flame Afterburner with Heat Exchanger); 131 (Thermal Oxidizer); 133 (Incinerator)					**Combustion zone temperature, oxygen concentration**, flue gas flow rate, auxiliary fuel supply rate, other specifications required by the equipment vendor, other parameters by permit (e.g. inlet/outlet pollutant concentrations).
021	Direct Flame Thermal Oxidizer (Thermal Incinerator)	NTE	021, 022, 131, 133	021 (Direct Flame Afterburner); 022 (Direct Flame Afterburner with Heat Exchanger); 131 (Thermal Oxidizer); 133 (Incinerator)					**Combustion zone temperature, oxygen concentration**, flue gas flow rate, auxiliary fuel supply rate, other specifications required by the equipment vendor, other parameters by permit (e.g. inlet/outlet pollutant concentrations).
023	Flaring	TE	023	023 (Flaring)					Parameters include: **combustion zone temperature indicating presence of a flame**, fuel flow rate, heat content, pollutant concentrations in the fuel and exhaust, and other parameters based on manufacturer's specifications.
023	Flaring	NTE	023	023 (Flaring)					Parameters include: **combustion zone temperature indicating presence of a flame**, fuel flow rate, heat content, pollutant concentrations in the fuel and exhaust, and other parameters based on manufacturer's specifications.
050	Packed Column - Gas Absorption	TE	050	050 (Packed-Gas Absorption Column)		85.0	99.0	92.0	**Scrubbing liquid flow rate and flue gas pressure drop** (scrubbing liquid pH, if needed).
050	Packed Column - Gas Absorption	NTE	050	050 (Packed-Gas Absorption Column)		68.0	79.2	73.6	**Scrubbing liquid flow rate and flue gas pressure drop** (scrubbing liquid pH, if needed).
073	Refrigerated Condenser	TE	073, 132	073 (Refrigerated Condenser); 132 (Condenser)					**Coolant temperature** and other manufacturer's specifications
073	Refrigerated Condenser	NTE	073, 132	073 (Refrigerated Condenser); 132 (Condenser)					**Coolant temperature** and other manufacturer's specifications

MPCA Code	CONTROL DEVICE/METHOD	TE/NTE	Applicable EPA Codes	Device Description	Record-keeping Requirements
	PM Controls:				
048	Adsorption: various adsorbents, including activated carbon, zeolites, molecular sieves, silicates, aluminas, synthetic resins, and lime	NTE	048, 084	048 (Activated Carbon Adsorption); 084 (Activated Clay Adsorption)	Daily readings of flue gas humidity, temperature, pressure drop; continuous or vendor-specified monitoring of inlet and outlet VOC concentrations; recording of carbon replacement or regeneration frequency.
506	Biofiltration	TE	506	New Device	Daily monitoring of bed temperature, moisture, nutrients (Nitrogen, phosphorus, potassium), pH, and inlet VOC concentration
506	Biofiltration	NTE	506	New Device	Daily monitoring of bed temperature, moisture, nutrients (Nitrogen, phosphorus, potassium), pH, and inlet VOC concentration
109	Catalytic Oxidizer (Catalytic Incinerator)	TE	019, 020, 109, 116	019 (Catalytic Afterburner); 020 (Catalytic Afterburner with Heat Exchanger); 109 (Catalytic Oxidizer); 116 (Catalytic Incinerator)	Recording of continuous temperature readouts, PM and oxygen concentrations, flue gas flow rate, and auxiliary fuel supply rate; other specifications recommended by the equipment vendors; source-specific requirements by permit (e.g. inlet/outlet pollutant concentrations).
109	Catalytic Oxidizer (Catalytic Incinerator)	NTE	019, 020, 109, 116	019 (Catalytic Afterburner); 020 (Catalytic Afterburner with Heat Exchanger); 109 (Catalytic Oxidizer); 116 (Catalytic Incinerator)	Recording of continuous temperature readouts, PM and oxygen concentrations, flue gas flow rate, and auxiliary fuel supply rate; other specifications recommended by the equipment vendors; source-specific requirements by permit (e.g. inlet/outlet pollutant concentrations).
074	Contact Condenser (Barometric Condenser)	TE	074, 132	074 (Barometric Condenser); 132 (Condenser)	Daily records of water flow rate and temperature, flue gas temperature
074	Contact Condenser (Barometric Condenser)	NTE	074, 132	074 (Barometric Condenser); 132 (Condenser)	Daily records of water flow rate and temperature, flue gas temperature
021	Direct Flame Thermal Oxidizer (Thermal Incinerator)	TE	021, 022, 131, 133	021 (Direct Flame Afterburner); 022 (Direct Flame Afterburner with Heat Exchanger); 131 (Thermal Oxidizer); 133 (Incinerator)	Recording of continuous temperature readouts, oxygen concentration, flue gas flow rate, and auxiliary fuel supply rate; other specifications recommended by the equipment vendors; source-specific requirements by permit (e.g. inlet/outlet pollutant concentrations).
021	Direct Flame Thermal Oxidizer (Thermal Incinerator)	NTE	021, 022, 131, 133	021 (Direct Flame Afterburner); 022 (Direct Flame Afterburner with Heat Exchanger); 131 (Thermal Oxidizer); 133 (Incinerator)	Recording of continuous temperature readouts, oxygen concentration, flue gas flow rate, and auxiliary fuel supply rate; other specifications recommended by the equipment vendors; source-specific requirements by permit (e.g. inlet/outlet pollutant concentrations).
023	Flaring	TE	023	023 (Flaring)	These include continuous combustion zone temperature readings, fuel flow rates, heat content, flare inlet and outlet pollutant concentrations (as required by permit), and other specifications required by the vendor for specific applications.
023	Flaring	NTE	023	023 (Flaring)	These include continuous combustion zone temperature readings, fuel flow rates, heat content, flare inlet and outlet pollutant concentrations (as required by permit), and other specifications required by the vendor for specific applications.
050	Packed Column - Gas Absorption	TE	050	050 (Packed-Gas Absorption Column)	Recording of scrubbing liquid flow rate and pressure drop every 24 hours (pH of scrubbing liquid, if needed).
050	Packed Column - Gas Absorption	NTE	050	050 (Packed-Gas Absorption Column)	Recording of scrubbing liquid flow rate and pressure drop every 24 hours (pH of scrubbing liquid, if needed).
073	Refrigerated Condenser	TE	073, 132	073 (Refrigerated Condenser); 132 (Condenser)	Continuous recording or hourly recording of coolant temperature and other specifications required by the manufacturers
073	Refrigerated Condenser	NTE	073, 132	073 (Refrigerated Condenser); 132 (Condenser)	Continuous recording or hourly recording of coolant temperature and other specifications required by the manufacturers

MPCA			Applicable		PM			PM10			PM2.5			SOx			NOx	
Code	CONTROL DEVICE/METHOD	TE/NTE	EPA Codes	Device Description	Low	High	Rep.	Low	High	Rep.	Low	High	Rep.	Low	High	Rep.	Low	High
	PM Controls:																	
051	Tray-Type Gas Absorption Column	TE	051	051 (Tray-Type Gas Absorption Column)										80.0	99.0	89.5	85.0	97.0
051	Tray-Type Gas Absorption Column	NTE	051	051 (Tray-Type Gas Absorption Column)										64.0	79.2	71.6	68.0	77.6
072	Tube and Shell Condenser	TE	072, 132	072 (Tube and Shell Condenser); 132 (Condenser)														
072	Tube and Shell Condenser	NTE	072, 132	072 (Tube and Shell Condenser); 132 (Condenser)														
507	Water blanket	TE	507	New Device														
507	Water blanket	NTE	507	New Device														
509	Regenerative Catalytic Oxidizer	TE	509	New Device	25.0	99.0	62.0	25.0	99.0	62.0								
509	Regenerative Catalytic Oxidizer	NTE	509	New Device	20.0	79.2	49.6	20.0	79.2	49.6								
510	Regenerative Thermal Oxidizer	TE	510	New Device	25.0	99.0	62.0	25.0	99.0	62.0								
510	Regenerative Thermal Oxidizer	NTE	510	New Device	20.0	79.2	49.6	20.0	79.2	49.6								
511	Flameless Thermal Oxidation	TE	511	New Device	25.0	99.0	62.0	25.0	99.9	62.5								
511	Flameless Thermal Oxidation	NTE	511	New Device	20.0	79.2	49.6	20.0	79.9	50.0								
512	Fluidized Bed Catalytic Incineration	TE	512	New Device	25.0	99.0	62.0	25.0	99.0	62.0								
512	Fluidized Bed Catalytic Incineration	NTE	512	New Device	20.0	79.2	49.6	20.0	79.2	49.6								
513	High Energy Corona	TE	513	New Device														
513	High Energy Corona	NTE	513	New Device														
082	Ozonation	TE	082	082 (Ozonation)														
082	Ozonation	NTE	082	082 (Ozonation)														
514	Photocatalytic Oxidation	TE	514	New Device														
514	Photocatalytic Oxidation	NTE	514	New Device														
515	Silent Discharge Plasma Technology	TE	515	New Device														

MPCA			Applicable			CO			VOC			VOT			POT			PIT	
Code	CONTROL DEVICE/METHOD	TE/NTE	EPA Codes	Device Description	Rep.	Low	High	Rep.	Low	High	Rep.	Low	High	Rep.	Low	High	Rep.	Low	High
	PM Controls:																		
051	Tray-Type Gas Absorption Column	TE	051	051 (Tray-Type Gas Absorption Column)	91.0				70.0	99.0	84.5	70.0	99.0	84.5					
051	Tray-Type Gas Absorption Column	NTE	051	051 (Tray-Type Gas Absorption Column)	72.8				56.0	79.2	67.6	56.0	79.2	67.6					
072	Tube and Shell Condenser	TE	072, 132	072 (Tube and Shell Condenser); 132 (Condenser)					50.0	90.0	70.0	50.0	90.0	70.0					
072	Tube and Shell Condenser	NTE	072, 132	072 (Tube and Shell Condenser); 132 (Condenser)					40.0	72.0	56.0	40.0	72.0	56.0					
507	Water blanket	TE	507	New Device					90.0	99.0	94.5	90.0	99.0	94.5					
507	Water blanket	NTE	507	New Device					72.0	79.2	75.6	72.0	79.2	75.6					
509	Regenerative Catalytic Oxidizer	TE	509	New Device		90.0	99.0	94.5	90.0	99.0	94.5	90.0	99.0	94.5	90.0	99.0	94.5		
509	Regenerative Catalytic Oxidizer	NTE	509	New Device		72.0	79.2	75.6	72.0	79.2	75.6	72.0	79.2	75.6	72.0	79.2	75.6		
510	Regenerative Thermal Oxidizer	TE	510	New Device		95.0	99.0	97.0	95.0	99.0	97.0	95.0	99.0	97.0	95.0	99.0	97.0		
510	Regenerative Thermal Oxidizer	NTE	510	New Device		76.0	79.2	77.6	76.0	79.2	77.6	76.0	79.2	77.6	76.0	79.2	77.6		
511	Flameless Thermal Oxidation	TE	511	New Device		99.0	99.9	99.5	99.0	99.9	99.5	99.0	99.9	99.5	99.0	99.9	99.5		
511	Flameless Thermal Oxidation	NTE	511	New Device		79.2	79.9	79.6	79.2	79.9	79.6	79.2	79.9	79.6	79.2	79.9	79.6		
512	Fluidized Bed Catalytic Incineration	TE	512	New Device		70.0	99.0	84.5	70.0	99.0	84.5	70.0	99.0	84.5	70.0	99.0	84.5		
512	Fluidized Bed Catalytic Incineration	NTE	512	New Device		56.0	79.2	67.6	56.0	79.2	67.6	56.0	79.2	67.6	56.0	79.2	67.6		
513	High Energy Corona	TE	513	New Device		90.0	99.0	94.5	90.0	99.0	94.5	90.0	99.0	94.5					
513	High Energy Corona	NTE	513	New Device		72.0	79.2	75.6	72.0	79.2	75.6	72.0	79.2	75.6					
082	Ozonation	TE	082	082 (Ozonation)					95.0	99.0	97.0	95.0	99.0	97.0					
082	Ozonation	NTE	082	082 (Ozonation)					76.0	79.2	77.6	76.0	79.2	77.6					
514	Photocatalytic Oxidation	TE	514	New Device		95.0	99.0	97.0	95.0	99.0	97.0	95.0	99.0	97.0					
514	Photocatalytic Oxidation	NTE	514	New Device		76.0	79.2	77.6	76.0	79.2	77.6	76.0	79.2	77.6					
515	Silent Discharge Plasma Technology	TE	515	New Device		95.0	99.0	97.0	95.0	99.0	97.0	95.0	99.0	97.0					

MPCA Code	CONTROL DEVICE/METHOD	TE/NTE	Applicable EPA Codes	Device Description	Rep.	GIT Low	GIT High	Rep.	Monitoring Parameter(s)
	PM Controls:								
051	Tray-Type Gas Absorption Column	TE	051	051 (Tray-Type Gas Absorption Column)		85.0	99.0	92.0	Could monitor one or more of the following: **scrubbing liquid flow rate, pressure drop**, pH of scrubbing liquid (if needed), water blowdown.
051	Tray-Type Gas Absorption Column	NTE	051	051 (Tray-Type Gas Absorption Column)		68.0	79.2	73.6	Could monitor one or more of the following: **scrubbing liquid flow rate, pressure drop**, pH of scrubbing liquid (if needed), water blowdown.
072	Tube and Shell Condenser	TE	072, 132	072 (Tube and Shell Condenser); 132 (Condenser)					**Coolant temperature** and flow rate
072	Tube and Shell Condenser	NTE	072, 132	072 (Tube and Shell Condenser); 132 (Condenser)					**Coolant temperature** and flow rate
507	Water blanket	TE	507	New Device					**Water level**
507	Water blanket	NTE	507	New Device					**Water level**
509	Regenerative Catalytic Oxidizer	TE	509	New Device					**Chamber temperature** and residence time or outlet VOC conc.
509	Regenerative Catalytic Oxidizer	NTE	509	New Device					**Chamber temperature** and residence time or outlet VOC conc.
510	Regenerative Thermal Oxidizer	TE	510	New Device					**Chamber temperature** and residence time or outlet VOC conc.
510	Regenerative Thermal Oxidizer	NTE	510	New Device					**Chamber temperature** and residence time or outlet VOC conc.
511	Flameless Thermal Oxidation	TE	511	New Device					**Chamber temperature** and residence time or outlet VOC conc.
511	Flameless Thermal Oxidation	NTE	511	New Device					**Chamber temperature** and residence time or outlet VOC conc.
512	Fluidized Bed Catalytic Incineration	TE	512	New Device					**Combustion temperature** or inlet and outlet temperatures; and catalyst bed reactivity as per manufacturer's specifications; residence time, adequate oxygen
512	Fluidized Bed Catalytic Incineration	NTE	512	New Device					**Combustion temperature** or inlet and outlet temperatures; and catalyst bed reactivity as per manufacturer's specifications; residence time, adequate oxygen
513	High Energy Corona	TE	513	New Device					**Electrical values (voltage, current)**
513	High Energy Corona	NTE	513	New Device					**Electrical values (voltage, current)**
082	Ozonation	TE	082	082 (Ozonation)					**Ozone concentration** and outlet VOC concentration for the Enhanced Carbon Adsorption; **Ozone concentration** and catalyst temperature for the catalytic oxidation
082	Ozonation	NTE	082	082 (Ozonation)					**Ozone concentration** and outlet VOC concentration for the Enhanced Carbon Adsorption; **Ozone concentration** and catalyst temperature for the catalytic oxidation
514	Photocatalytic Oxidation	TE	514	New Device					**Presence of ultra-violet light**, inlet and outlet VOC concentrations
514	Photocatalytic Oxidation	NTE	514	New Device					**Presence of ultra-violet light**, inlet and outlet VOC concentrations
515	Silent Discharge Plasma Technology	TE	515	New Device					**Electrical values (voltage, current)**

MPCA Code	CONTROL DEVICE/METHOD	TE/NTE	Applicable EPA Codes	Device Description	Record-keeping Requirements
	PM Controls:				
051	Tray-Type Gas Absorption Column	TE	051	051 (Tray-Type Gas Absorption Column)	Daily records of one or more of the following: scrubbing liquid flow rate, pH of scrubbing liquid (if needed), pressure drop, water blowdown.
051	Tray-Type Gas Absorption Column	NTE	051	051 (Tray-Type Gas Absorption Column)	Daily records of one or more of the following: scrubbing liquid flow rate, pH of scrubbing liquid (if needed), pressure drop, water blowdown.
072	Tube and Shell Condenser	TE	072, 132	072 (Tube and Shell Condenser); 132 (Condenser)	Continuous recording or hourly recording of coolant temperature and other specifications required by the manufacturers
072	Tube and Shell Condenser	NTE	072, 132	072 (Tube and Shell Condenser); 132 (Condenser)	Continuous recording or hourly recording of coolant temperature and other specifications required by the manufacturers
507	Water blanket	TE	507	New Device	Daily readings of water level
507	Water blanket	NTE	507	New Device	Daily readings of water level
509	Regenerative Catalytic Oxidizer	TE	509	New Device	Continuous recording or hourly recording of chamber temperature and residence time or outlet VOC conc.
509	Regenerative Catalytic Oxidizer	NTE	509	New Device	Continuous recording or hourly recording of chamber temperature and residence time or outlet VOC conc.
510	Regenerative Thermal Oxidizer	TE	510	New Device	Continuous recording or hourly recording of chamber temperature and residence time or outlet VOC conc.
510	Regenerative Thermal Oxidizer	NTE	510	New Device	Continuous recording or hourly recording of chamber temperature and residence time or outlet VOC conc.
511	Flameless Thermal Oxidation	TE	511	New Device	Continuous recording or hourly recording of chamber temperature and residence time or outlet VOC conc.
511	Flameless Thermal Oxidation	NTE	511	New Device	Continuous recording or hourly recording of chamber temperature and residence time or outlet VOC conc.
512	Fluidized Bed Catalytic Incineration	TE	512	New Device	Continuous recording or hourly recording of combustion temperature or inlet and outlet temperatures; and catalyst bed reactivity as per manufacturer's specifications; residence time, adequate oxygen
512	Fluidized Bed Catalytic Incineration	NTE	512	New Device	Continuous recording or hourly recording of combustion temperature or inlet and outlet temperatures; and catalyst bed reactivity as per manufacturer's specifications; residence time, adequate oxygen
513	High Energy Corona	TE	513	New Device	Continuous recording of electrical values (voltage, current)
513	High Energy Corona	NTE	513	New Device	Continuous recording of electrical values (voltage, current)
082	Ozonation	TE	082	082 (Ozonation)	Continuous recording of ozone concentration and catalyst temperature, recording of carbon replacement or regeneration frequency, and outlet VOC concentration for the Enhanced Carbon Adsorption system; Continuous recording of ozone concentration and catalyst temperature for the catalytic oxidation system
082	Ozonation	NTE	082	082 (Ozonation)	Continuous recording of ozone concentration and catalyst temperature, recording of carbon replacement or regeneration frequency, and outlet VOC concentration for the Enhanced Carbon Adsorption system; Continuous recording of ozone concentration and catalyst temperature for the catalytic oxidation system
514	Photocatalytic Oxidation	TE	514	New Device	Continuous recording of presence of ultra-violet light, inlet and outlet VOC concentrations
514	Photocatalytic Oxidation	NTE	514	New Device	Continuous recording of presence of ultra-violet light, inlet and outlet VOC concentrations
515	Silent Discharge Plasma Technology	TE	515	New Device	Continuous recording of electrical values (voltage, current)

MPCA			Applicable			PM			PM10			PM2.5			SOx			NOx
Code	CONTROL DEVICE/METHOD	TE/NTE	EPA Codes	Device Description	Low	High	Rep.	Low	High	Rep.	Low	High	Rep.	Low	High	Rep.	Low	High
	PM Controls:																	
515	Silent Discharge Plasma Technology	NTE	515	New Device														
047	Vapor Recovery System (Stage I) - Bulk Plants	NTE	047	047 (Vapor Recovery Sys (Incl. Condensers, Hooding, Other Enclosures)														
508	Cryogenic Condensation	TE	508	New Device														
508	Cryogenic Condensation	NTE	508	New Device														
	NOx Controls:																	
140	Non-Selective Catalytic Reduction, Rich Burn Engines	TE	065, 140	065 (Catalytic Reduction); 140 (NSCR (Non-Selective Catalytic Reduction))													90.0	95.0
139	Selective Catalytic Reduction	TE	065, 139	065 (Catalytic Reduction); 139 (SCR (Selective Catalytic Reduction))													80.0	90.0
032	Selective Non-Catalytic Reduction, Boilers	TE	032, 107	032 (Ammonia Injection); 107 (Selective Non Catalytic Reduction for NOx)													30.0	70.0
032	Selective Non-Catalytic Reduction, Process Heaters	TE	032, 107	032 (Ammonia Injection); 107 (Selective Non Catalytic Reduction for NOx)													20.0	50.0
516	Thermal Reduction, Adipic Acid	TE	516	New Device													70.0	95.0
516	Thermal Reduction, Adipic Acid	NTE	516	New Device													56.0	76.0

MPCA			Applicable		CO			VOC			VOT			POT			PIT		
Code	CONTROL DEVICE/METHOD	TE/NTE	EPA Codes	Device Description	Rep.	Low	High	Rep.	Low	High	Rep.	Low	High	Rep.	Low	High	Rep.	Low	High
	PM Controls:																		
515	Silent Discharge Plasma Technology	NTE	515	New Device		76.0	79.2	77.6	76.0	79.2	77.6	76.0	79.2	77.6					
047	Vapor Recovery System (Stage I) - Bulk Plants	NTE	047	047 (Vapor Recovery Sys (Incl. Condensers, Hooding, Other Enclosures)					90.0	95.0	92.5	90.0	95.0	92.5					
508	Cryogenic Condensation	TE	508	New Device					95.0	99.0	97.0	95.0	99.0	97.0					
508	Cryogenic Condensation	NTE	508	New Device					76.0	79.2	77.6	76.0	79.2	77.6					
	NOx Controls:																		
140	Non-Selective Catalytic Reduction, Rich Burn Engines	TE	065, 140	065 (Catalytic Reduction); 140 (NSCR (Non-Selective Catalytic Reduction))	92.5														
139	Selective Catalytic Reduction	TE	065, 139	065 (Catalytic Reduction); 139 (SCR (Selective Catalytic Reduction))	85.0														
032	Selective Non-Catalytic Reduction, Boilers	TE	032, 107	032 (Ammonia Injection); 107 (Selective Non Catalytic Reduction for NOx)	50.0														
032	Selective Non-Catalytic Reduction, Process Heaters	TE	032, 107	032 (Ammonia Injection); 107 (Selective Non Catalytic Reduction for NOx)	40.0														
516	Thermal Reduction, Adipic Acid	TE	516	New Device	82.5														
516	Thermal Reduction, Adipic Acid	NTE	516	New Device	66.0														

MPCA			Applicable			GIT			Monitoring
Code	CONTROL DEVICE/METHOD	TE/NTE	EPA Codes	Device Description	Rep.	Low	High	Rep.	Parameter(s)
	PM Controls:								
515	Silent Discharge Plasma Technology	NTE	515	New Device					**Electrical values (voltage, current)**
047	Vapor Recovery System (Stage I) - Bulk Plants	NTE	047	047 (Vapor Recovery Sys (Incl. Condensers, Hooding, Other Enclosures)					**VOC Leakage**
508	Cryogenic Condensation	TE	508	New Device					**Nitrogen flow rate, reactor temperature**
508	Cryogenic Condensation	NTE	508	New Device					**Nitrogen flow rate, reactor temperature**
	NOx Controls:								
140	Non-Selective Catalytic Reduction, Rich Burn Engines	TE	065, 140	065 (Catalytic Reduction); 140 (NSCR (Non-Selective Catalytic Reduction))					**Temperature, oxygen concentration**
139	Selective Catalytic Reduction	TE	065, 139	065 (Catalytic Reduction); 139 (SCR (Selective Catalytic Reduction))					**Ammonia or urea level**, discharge level of NOx, temperature, and other manufacturer's specifications
032	Selective Non-Catalytic Reduction, Boilers	TE	032, 107	032 (Ammonia Injection); 107 (Selective Non Catalytic Reduction for NOx)					**Ammonia or urea level**, discharge level of NOx , temperature
032	Selective Non-Catalytic Reduction, Process Heaters	TE	032, 107	032 (Ammonia Injection); 107 (Selective Non Catalytic Reduction for NOx)					**Ammonia or urea level**, discharge level of NOx , temperature
516	Thermal Reduction, Adipic Acid	TE	516	New Device					**Temperature, fuel to NOx ratio**, and other manufacturer's specifications
516	Thermal Reduction, Adipic Acid	NTE	516	New Device					**Temperature, fuel to NOx ratio**, and other manufacturer's specifications

MPCA Code	CONTROL DEVICE/METHOD	TE/NTE	Applicable EPA Codes	Device Description	Record-keeping Requirements
	PM Controls:				
515	Silent Discharge Plasma Technology	NTE	515	New Device	Continuous recording of electrical values (voltage, current)
047	Vapor Recovery System (Stage I) - Bulk Plants	NTE	047	047 (Vapor Recovery Sys (Incl. Condensers, Hooding, Other Enclosures)	Results of daily or monthly leakage detection
508	Cryogenic Condensation	TE	508	New Device	Daily readings of nitrogen flow rate, reactor temperature
508	Cryogenic Condensation	NTE	508	New Device	Daily readings of nitrogen flow rate, reactor temperature
	NOx Controls:				
140	Non-Selective Catalytic Reduction, Rich Burn Engines	TE	065, 140	065 (Catalytic Reduction); 140 (NSCR (Non-Selective Catalytic Reduction))	Continuous reading of temperature and oxygen concentration
139	Selective Catalytic Reduction	TE	065, 139	065 (Catalytic Reduction); 139 (SCR (Selective Catalytic Reduction))	Record each parameter every 24 hours and other specifications required by the manufacturers
032	Selective Non-Catalytic Reduction, Boilers	TE	032, 107	032 (Ammonia Injection); 107 (Selective Non Catalytic Reduction for NOx)	Daily records each parameter and ratio of NOx to ammonia or urea
032	Selective Non-Catalytic Reduction, Process Heaters	TE	032, 107	032 (Ammonia Injection); 107 (Selective Non Catalytic Reduction for NOx)	Daily records each parameter and ratio of NOx to ammonia or urea
516	Thermal Reduction, Adipic Acid	TE	516	New Device	Continuous reading of temperature, fuel to NOx ratio, and other specifications required by the manufacturers
516	Thermal Reduction, Adipic Acid	NTE	516	New Device	Continuous reading of temperature, fuel to NOx ratio, and other specifications required by the manufacturers