IDENTIFICATION OF POINT SOURCE EMISSION CONTROLS AND DETERMINATION OF THEIR EFFICIENCIES AND COSTS

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Prepared for:

California Air Resources Board
and the California Environmental Protection Agency
Sacramento, CA 95814

Contract No. 96-325
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ABSTRACT

The California Air Resources Board (CARB) is responsible for compiling a statewide air pollutant emissions inventory and improving the inventory as necessary to meet its objectives and those of its emissions inventory clients (e.g., local air quality districts). As part of this process, CARB requires a comprehensive, up-to-date list of air pollution controls that are used for reducing emissions from point sources and the accompanying range of control efficiencies typically achieved for each pollutant. Among other uses, this information is used by CARB and local air district staff during the evaluation of permit applications and emission inventory reporting.

By 1997, the point source control listing that was in use by CARB and the districts had become out of date (e.g., newer controls were not represented, ranges of control efficiencies were overly broad). To update this listing, a comprehensive review of relevant air pollution data sources was conducted. Among these sources were:

- the United States Environmental Protection Agency's (EPA's) AP-42, Control Techniques Guidelines, Alternative Control Technique documents, and other reports on control equipment for criteria and hazardous air pollutants (HAPs, also referred to as air toxics);
- the State and Territorial Air Pollution Program Administrators/Association of Local Air Pollution Control Officials control technology reports;
- the California Air Pollution Control Officers' Association's Reasonably Available Control Technology/Best Available Control Technology clearinghouse;
- standard air pollution references (e.g., the *Air Pollution Engineering Manual*);
- in-house control technology assessments previously prepared by E.H. Pechan & Associates, Inc.; and
- recent technical literature including the Air and Waste Management Association technical papers, periodicals, the internet, and telephone contacts (EPA, trade organizations, and manufacturers).

The data gathered from these sources were used in developing descriptions of each control technology and establishing the expected control efficiency range achieved in actual practice. Where available, information on the costs of these controls, in terms of cost effectiveness (annualized cost per ton of pollutant reduced, in 1995 dollars), was incorporated into the control description. Information for most of the commonly used equipment were well documented and based on in-depth studies. Data for less-used and emerging technology equipment were often sparse and/or vague. In many of these cases, it was necessary to apply professional judgment in establishing efficiency ranges and costs.

An updated printout of CARB's database of point source air pollution controls is contained in this report as well as descriptions of the control technologies, ranges of typical operating control efficiencies, and available cost data. A limited effort was made to incorporate information on point source control of air toxics. This effort included the development of an appendix which lists all California air toxics and EPA HAPs and defines each as a volatile organic toxic, a particulate organic toxic, a particulate inorganic toxic, a gaseous inorganic toxic, or some combination of these categories. This toxics categorization scheme can then be used to assign approximate control ranges for many of the control technologies presented in this report.

During the study, researchers strived to provide estimates of reasonable upper and lower bounds on the control efficiencies. Whenever possible, these ranges were based on test data, however, in many cases, professional judgement was used to establish a reasonable range. Therefore, the user should be cautioned that, in any given situation, a control technology could achieve efficiencies outside of the estimated range. For assessments dealing with permit review, risk assessment, and other regulatory studies, testing of the source should be required.

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EXECUTIVE SUMMARY

The California Air Resources Board (CARB) is responsible for compiling a statewide air pollutant emissions inventory and improving the inventory as necessary to meet its objectives and those of its emissions inventory clients (e.g., local air quality districts). As part of this process, CARB requires a comprehensive, up-to-date list of air pollution controls that are used for reducing emissions from point sources and the accompanying range of control efficiencies typically achieved for each pollutant.

The current list of control technology codes used by CARB was developed by the United States Environmental Protection Agency (EPA) over 15 years ago for use in the National Emissions Data System and does not include cost data. Due to the age of this listing (hereafter referred to as the control technology database), a number of new technologies do not appear, or have to be considered as being a part of a much more broad category. In addition, the control efficiency data are outdated or the range is so broad that the information is of limited value. Finally, the existing control data only apply to criteria pollutants. CARB would also like to include information on control of air toxics (however, only a small portion of the resources allocated to this project were to be used in assessing control efficiencies for air toxics).

The contents of this report include: a printout of an update to the control technology database; a description of the control technologies covered; ranges of typical control efficiencies for each control technology; and available cost data range in terms of cost effectiveness (i.e., annualized costs per ton of pollutant reduced, in 1995 dollars).

To update the existing control technology database, a comprehensive review of relevant air pollution data sources was conducted. Among these sources were:

- the EPA's AP-42, Control Technique Guidelines, Alternative Control Technique documents, and other reports on control equipment for criteria and hazardous air pollutants (also referred to as air toxics);
- the State and Territorial Air Pollution Program Administrators/Association of Local Air Pollution Control Officials control technology reports;
- the California Air Pollution Control Officers' Association's Reasonably Available Control Technology/Best Available Control Technology clearinghouse;
- standard air pollution references (e.g., the *Air Pollution Engineering Manual*);
- in-house control technology assessments previously prepared by E.H. Pechan & Associates, Inc. (Pechan); and

- recent technical literature including the Air and Waste Management Association technical papers, periodicals, the internet, and telephone contacts (EPA, trade organizations, and manufacturers).

The data gathered from these sources were used in preparing descriptions of each control device, and establishing the expected control efficiency range and cost effectiveness (in 1995 dollars) achieved in practice. Information for most of the commonly-used control technologies were well documented and are based on in-depth studies. Data for less-used and emerging technologies were often sparse and/or vague. In many of these cases, it was necessary to apply professional judgment in establishing efficiency ranges and costs. In some cases, costs could not be determined.

The air pollutants addressed in this study include three groups of particulate matter. These are total suspended particulate, or TSP (referred to in this report as simply "particulate matter," or PM), particulate matter less than 10 microns in diameter, and particulate matter less than 2.5 microns. The other pollutants addressed are oxides of sulfur, oxides of nitrogen, carbon monoxide, total organic gases, reactive organic gases, and air toxics.

While CARB desired to include available information on the efficiencies of various technologies in controlling air toxics emissions, a limited effort was to be made in gathering this data. To assist a user in assessing air toxics control efficiencies, a categorization scheme was developed for toxics based on similar chemical and physical characteristics. This categorization scheme involved grouping each California- or EPA-listed toxic in one or more of the four following categories: volatile organic toxics; particulate organic toxics; particulate inorganic toxics; and gaseous inorganic toxics.

Control efficiencies are presented for the primary pollutant that the technology is designed to control. Some technologies may incidentally control other pollutants, and, where data are available, efficiency ranges are presented. In general, control efficiencies are expressed in whole numbers. Where sufficient documentation exists, control efficiencies greater than 99 percent are expressed in tenths of a percent, however most are expressed as ">99.0 %". For most equipment capable of operating at >99.0 percent efficiency, there is usually a wide enough variation, that it is not practical to establish a reasonable and representative upper level of control efficiency in tenths of a percent with any certainty.

In the original CARB control technology database, five pollutants were addressed and 95 control technologies were listed. The updated list addresses 12 pollutant types and approximately 350 control technologies and control technology combinations.

The new control technology listing represents an improvement in that the range between low and high control efficiency has been narrowed, in many cases, compared to the previous version. Aside from the incorporation of new data, this is also due to several other reasons:

1. the low end of control efficiency of many pieces of equipment has been increased due to upgrades and more stringent specifications by industry in order to meet more stringent regulations,

2. broad control technology groups have been broken down into more specific types of equipment/applications,

3. the addition of new, higher-efficiency control equipment developed in recent years, and

4. the removal of some devices and/or control efficiency data because they were not deemed to be primary control equipment for the pollutant identified, or no data could be located on the equipment, most likely because the technology is no longer widely-used.

During the study, researchers strived to provide estimates of reasonable upper and lower bounds on the control efficiencies. Whenever possible, these ranges were based on test data, however, in many cases, professional judgement was used to establish a reasonable range. Therefore, the user should be cautioned that, in any given situation, a control technology could achieve efficiencies outside of the estimated range. For assessments dealing with permit review, risk assessment, and other regulatory studies, testing of the source should be required.

CHAPTER I. INTRODUCTION

The California Air Resources Board (CARB) is responsible for compiling a statewide air pollutant emissions inventory and improving the inventory as necessary to meet its objectives and those of its emissions inventory clients (e.g., local air quality districts). As part of this process, CARB requires a comprehensive, up-to-date list of air pollution control technologies that are used for reducing emissions from point sources and the accompanying range of control efficiencies typically achieved for each pollutant. Within this listing, each control technology is assigned a three digit code referred to as a control technology code (CTC).

The current control technology database used by CARB was developed by the United States Environmental Protection Agency (EPA) over 15 years ago for use in the National Emissions Data System (NEDS) and does not include cost data. Due to the age of this listing, a number of new technologies do not appear, or have to be considered as being a part of a much more broad category. In addition, the control efficiency data are outdated or the range is so broad that the information is of limited value. Finally, the existing control data only apply to criteria pollutants. CARB would also like to include information on control of air toxics (however, only a small portion of the resources allocated to this project were to be used in assessing control efficiencies for air toxics).

Point source control technologies for the following air pollutants are addressed in this study:

- three groups of particulate matter - total suspended particulate (TSP) (referred to in this report as simply "PM"), particulate matter less than 10 microns in diameter (PM10), and particulate matter less than 2.5 microns (PM2.5);
- oxides of sulfur (SOx);
- oxides of nitrogen (NOx);
- carbon monoxide (CO);
- total organic gases (TOG) and reactive organic gases (ROG); and
- air toxics grouped into four categories depending on physical and chemical properties - volatile organic toxics (VOT), particulate organic toxics (POT), particulate inorganic toxics (PIT), and gaseous inorganic toxics (GIT).

The methods and data sources used to conduct the control technology research are described in Chapter II. Methods used to assess control efficiencies of air toxics are also outlined in this chapter. Research results, including an overview of control technologies for criteria air pollutants, are presented in Chapter III. A printout of the revised control technology database, including the control technology name and the range of control

efficiencies that can be expected during actual operating conditions, is presented in Appendix A. Control technology descriptions and costs corresponding to the technologies listed in the control technology database are presented in Appendix B. Both California (Assembly Bill 2588) and Federal Clean Air Act Title III air toxics are classified as to toxics type (i.e., VOT, POT, PIT, or GIT) in Appendix C.

CHAPTER II. METHODS AND DATA SOURCES

A. DEVELOPMENT OF POINT SOURCE CONTROL TECHNOLOGY INFORMATION

The point source control technologies database currently in use by CARB and California air districts was developed by EPA over 15 years ago for use in the NEDS. By 1997, this database had become out of date (e.g., newer controls were not represented, ranges of control efficiencies were overly broad). In addition, no information on the cost of control technologies is included in the existing database. To update this listing, a comprehensive review of relevant air pollution data sources was conducted. Among these sources were:

- the EPA's AP-42, Control Technique Guidelines, Alternative Control Technique documents, and other reports on control equipment for criteria and hazardous air pollutants (HAPs, also referred to as air toxics);
- the State and Territorial Air Pollution Program Administrators/Association of Local Air Pollution Control Officials (STAPPA/ALAPCO) control technology reports;
- the California Air Pollution Control Officers' Association's Reasonably Available Control Technology/Best Available Control Technology Clearinghouse;
- standard air pollution references (e.g., the *Air Pollution Engineering Manual*);
- in-house control technology assessments previously prepared by Pechan; and
- recent technical literature including the Air and Waste Management Association (AWMA) technical papers, periodicals, the internet, and telephone contacts (EPA, trade organizations, and manufacturers).

The data gathered from these sources were used in preparing descriptions of each control technology, and establishing the expected control efficiency range and cost effectiveness (annualized cost per ton of pollutant reduced) achieved in practice. Information for most of the commonly-used control technologies were well documented and based on in-depth studies, however, professional judgement was still necessary, especially in establishing control ranges for equipment combinations. Data for less-used and emerging technologies were often sparse and/or vague; professional judgment was applied in establishing efficiency ranges.

Cost effectiveness is expressed in 1995 dollars, unless otherwise noted. When cost effectiveness data in the literature was based on a year earlier than 1995, escalation factors were applied to convert to 1995 dollars. At times, the only available cost data were expressed in units such as dollars/scfm or dollars/megawatt of electricity, and assumptions and professional judgement were necessary to convert to dollars/ton of pollutant reduced. In some cases, costs could not be determined. It should be noted that only 5% of the project

effort was devoted to developing cost data. Actual annualized cost data may vary greatly, depending on the specific case.

The air pollutants addressed in this study include three groups of particulate matter. These are PM (i.e., TSP), PM10, and PM2.5. The other pollutants addressed are SOx, NOx, CO, TOG, ROG, and air toxics (methods for establishing control efficiencies for air toxics are given in the next section).

B. METHODS FOR ASSESSING CONTROL EFFICIENCIES FOR AIR TOXICS

As part of this project, a limited effort was made to include control efficiency data for air toxics. Few controls are in use today that were designed specifically for the control of air toxics. Control of toxics emissions is generally done with technologies originally designed to control criteria pollutants [e.g., volatile organic compounds (VOC) and PM]. These controls are described in Chapter III and Appendix B. One recent exception is the use of carbon injection technology for the control of mercury (Hg) and dioxin/furan emissions from municipal and medical waste incinerators. Additional details on carbon injection can be found in Appendix B.

For the purpose of assigning toxics control efficiencies to the various technologies described in this study, it was necessary to characterize air toxics by the physical and chemical properties that relate to their control (e.g., whether they are an aerosol or gas, organic/inorganic). The first step to accomplish this was to expand the control technology database by an additional eight fields to account for the upper and lower end of the efficiency range for four toxics types:

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

The second step was to assign each air toxic to one or more of the four types described above. Pollutants listed as HAPs under Section 112 of the Clean Air Act and air toxics listed in California's AB2588 program are presented in Appendix C. In some cases, a secondary type 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.

Various criteria were used in the assignment of each toxic to the four toxics types as presented in Appendix C. Among these were previous experience working with emissions of a toxics species, vapor pressure [e.g., >1 millimeters of Hg column @ 20 degrees Celcius (°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 largely 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.

Users should be extremely careful in assigning control efficiencies using the toxics categorization scheme when dealing with toxics that can take on more than one form (see Appendix C). Also, users should consult the technology descriptions or other literature to ascertain whether the control technology is limited to certain species. For example, the carbon injection control technology is listed as having control efficiencies for POT, PIT, and GIT, however these control efficiencies have only been documented for dioxin/furans (i.e., not all POT) and Hg (i.e., not all PIT or GIT).

There are several limitations to the assignment of toxics into the four general types and assumptions of control efficiency. Limitations include the following:

- *inter-species variability within a toxics type*: for example, some organic toxics are more resistant to thermal oxidation than others. Hence, for a given temperature and residence time some toxics will be combusted with a higher efficiency than others. As an illustration, sample groupings of several toxics are shown in Table 1 (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.

- *partitioning between phases and/or elemental forms*: as mentioned above, some toxics can exist as both a gas and an aerosol (particle). Important among these are semi-volatile organics (such as some dioxins/furans and PAHs) and Hg.

Due to these limitations, it is recommended that caution be used in assigning control efficiencies to toxics species, and that the analyst consider use of the lower end of the

reported range for conservatism. Also, for such uses as input to health and ecological risk assessments, test data of the source under consideration should always be used instead of the values in the current database. As more data specific to control of various toxics become available, the database can be updated to reflect this improved data.

Table 1
Sample Air Toxics Grouped by Ease of Destruction

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

(adapted from Pennington, 1996)

CHAPTER III. RESULTS OF CONTROL TECHNOLOGY RESEARCH

A. METHODS OF AIR POLLUTION CONTROL

Methods for controlling air pollution from point sources include add-on controls, process controls, and integrated controls:

1. *Add-on control*: This type of control typically includes a piece of equipment (e.g., a baghouse) that is added to the exhaust stream.

2. *Process control*: A process control involves a change or modification to an industrial process that would result in a reduction in the emissions generated by a process (e.g., a change from top filling of fuels to bottom filling).

3. *Integrated control*: An integrated control is incorporated into the design of the equipment that produces emissions (e.g., a low-NOx burner).

Modifications that are made to change how a product is produced or handled are in the process control category; such as solvent recovery and re-use, change in fuel type, how fuel is stored and delivered, and modifications to storage facilities, such as tanks. Usually, a process control also implies at least some small benefit to the overall system (fuel or product conservation, less toxic exposure for workers, etc.).

Integrated controls are equipment modifications that are made strictly for the purpose of reducing emissions [e.g., burner design, flue gas recirculation (FGR)].

A general discussion of the types of point source control technologies used for criteria pollutants is given below. For more detailed technology descriptions and listings of the references cited, see Appendix B.

B. POINT SOURCE CONTROL EFFICIENCIES

A printout of the revised control technology database is given in Appendix A. The results of this research effort provided a significant expansion in the coverage of point source pollution controls. Some technologies from the existing database were dropped due to inappropriate nomenclature, or because the technology had become obsolete and there were no indications of current usage. Comparisons between the existing and revised control technology databases are given in Table 2.

Table 2
Comparison of Existing and Revised Control Technology Databases

Parameter	Existing Database	Revised Database
Pollutants Covered	PM, VOC, NOx, SOx, CO	PM, PM10, PM2.5, TOG, ROG, CO, NOx, SOx, VOT, POT, PIT, GIT
Add-on Controls	68	106
Process Controls	18	17
Integrated Controls	9	51
Control Combinations	0	181
Total Controls	**95**	**355**

The control efficiencies are presented in order of the primary pollutant that the technology is designed to control. Some technologies incidentally control other pollutants and, where adequate documentation exists, control efficiency ranges are presented. The three-digit codes assigned to each control technology in the database are ordered by control method and primary pollutant controlled as follows:

- **001 - 399** **Add-on Control Technologies**

  001 - 079 PM, PM10, PM2.5
  080 - 159 SOx
  160 - 239 NOx
  240 - 319 TOG, ROG, VOT
  320 - 399 Open

- **400 - 599** **Process Controls**

  400 - 429 PM, PM10, PM2.5
  430 - 449 NOx
  450 - 479 TOG, ROG, VOT
  480 - 599 Open

- **600 - 699** **Integrated Controls**

  600 - 679 NOx
  680 - 699 Open

- **700 - 999** **Control Combinations**

  700 - 749 NOx
  750 - 949 PM, PM10, PM2.5
  921 - 999 Open

In general, control efficiencies are expressed in whole numbers. Some control efficiencies greater than 99 percent are expressed in tenths of a percent, however most are expressed as ">99.0%". For most equipment capable of operating at >99.0 percent efficiency, there is often a wide variation in performance in the 99 to 100 percent range. Therefore, with available data, it is not practical in most cases to establish a representative upper level of control efficiency in tenths of a percent with any certainty. In cases where good data was available to show an upper range of greater than 99.5 percent, this value was selected for use in the database. Similarly when sufficient data showed an upper range in excess of 99.9 percent, this value was selected. Due to the variability for many controls, researchers did not feel that establishing efficiencies with intermediate values (e.g., 99.3, 99.7) was warranted.

For the purpose of this study, the collection efficiency (the amount of emissions delivered to an add-on control device divided by the amount generated by the source, expressed as a percent) is assumed to be 100 percent. That is, the control efficiencies reported are based on the amount of emissions actually treated by the equipment. The control efficiencies also do not reflect a lower bound that could represent "upset conditions" (i.e., all ranges are based on typical operating conditions).

During the study, researchers strived to provide estimates of reasonable upper and lower bounds on the control efficiencies. Whenever possible, these ranges were based on test data, however, in many cases, professional judgement was used to establish a reasonable range. Therefore, the user should be cautioned that, in any given situation, a control technology could achieve efficiencies outside of the estimated range. For assessments dealing with permit review, risk assessment, and other regulatory studies, testing of the source should be required.

C. CONTROL TECHNOLOGY DESCRIPTIONS

Detailed descriptions on control technologies and available cost data are given in Appendix B. The following subsections provide general descriptions of the more common control technologies covered during this study.

1. PM Control Technologies

PM is generated by combustion and other industrial processes. In most cases, PM is collected after it has been generated, hence, virtually all PM controls are add-on controls.

a. Precleaning Devices

Mechanical collectors are a broad class of PM control devices that use either gravity settling and/or inertial impaction mechanisms to remove large and/or dense particles from flue gas streams. Because their performance capability is limited to the removal of large and/or dense particles from gas streams and regulatory requirements have become more stringent, they are now used primarily as pretreatment devices to reduce the PM loading on fabric filters, electrostatic precipitators (ESPs), and scrubbers. However, some types of collectors may provide adequate control of PM for some applications as a stand alone collection device or in series combination.

There is great diversity in the design and operating principles of the various types of mechanical collectors. Mechanical collectors include gravity settling chambers, momentum separators, centrifugal collectors, and single and multiple cyclones.

b. Fabric Filters

Fabric filters are add-on controls that are used in a wide variety of industrial and commercial applications to control primary PM emissions. Fabric filters remove dust from a gas stream by passing the stream through a porous fabric. Fabric filters are frequently referred to as baghouses because the fabric is usually configured in cylindrical bags. When they can be applied to control PM emissions for a particular emission source (i.e., excessive heat or incompatible exhaust constituents are not present), fabric filters are considered to provide superior control of fine PM relative to other control devices (e.g., ESPs and scrubbers).

c. Gravel- or Granular-bed Filters

Gravel-bed filters were developed for use in controlling emissions from high-temperature flue gas streams to remove fine PM and smoke particles. The advantage of the gravel-bed filter relative to a fabric filter is its ability to tolerate high-temperature gas streams containing combustible constituents and/or high moisture contents. The typical set up involves drawing exhaust gas through a bed of pea gravel which traps the PM. The bed is cleaned either continuously or intermittently depending on the design of the unit. They are also used where control of fine PM would require a scrubber to operate at a high pressure drop to obtain the same level of control.

An alternative design of the gravel-bed filter involves the use of a slow, moving bed of granular rock as the filtration medium. To enhance collection efficiency, moving bed filters have been electrostatically charged. Gravel-bed moving filters are also called granular-bed moving filters.

d. Electrostatic Precipitators

ESPs are add-on control devices that are designed to remove PM from the flue gas stream using electrical fields. ESPs may be designed and operated as dry or wet units. Dry units typically are used to control large gas volumes, such as electric utility coal-fired boilers. Wet ESP technology has been developed more recently than dry ESP technology. Wet ESPs are used to control relatively smaller gas volumes than dry ESPs, and on flue gas streams containing fumes or mist which may be difficult to control with a dry ESP or fabric filter.

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. The most common ESP designs are wire-plate and wire-pipe collectors, but rigid frame-plate designs are also used.

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. ESP size is also related to the ratio of the surface

area of the collection electrodes to the gas flow (the specific collection area). Maximizing electric field strength will maximize ESP collection efficiency.

e. Wet Scrubbers

Wet scrubbers are add-on control devices that are used to remove PM from gas by capturing the particles in liquid (usually water) droplets, foam, or bubbles, and separating the droplets from the gas stream. The droplets act as conveyors of the PM out of the gas stream. With wet scrubbers, PM and soluble gases can be removed simultaneously. Wet scrubbers capture PM through three primary mechanisms: (1) *impaction* of the particle directly into a target droplet; (2) *interception* of the particle by the target droplet as the particle nears the droplet; and (3) *diffusion* of the particle through the gas surrounding the target droplet until the particle is close enough to be captured. Other scrubber collection mechanisms include gravitation, electrostatics, and condensation. The dominant means of PM capture in most industrial wet scrubbers is inertial impaction.

Wet scrubbers are classified by the method used to induce the contact between the liquid and the PM. The major categories of wet scrubbers are: spray chamber scrubbers, also referred to as spray towers; packed-bed scrubbers; tray-type scrubbers; mechanically-aided scrubbers; venturi and orifice scrubbers; condensation scrubbers; and charged scrubbers.

Wet scrubbers are used under circumstances where the contaminant cannot be removed easily in a dry form; soluble gases are present; soluble or wettable PM is present; the contaminant will undergo some subsequent wet process (such as recovery, wet separation or settling, or neutralization); the pollution control system must be compact; or where the contaminants are most safely handled wet rather than dry (i.e., where the dry PM may ignite or explode).

f. Mist Eliminators

Mist eliminators are used to eliminate mist (fine liquid droplets) from carrying pollutants out of scrubber stacks; however, they can also be used as stand-alone control devices to control acid mists. There are two general types of mist eliminators: 1) blade-type, consisting of one or more sets of parallel, chevron-shaped baffles (blades), and 2) mesh-pad, which are made up of densely-packed layers of interlocked filaments. The principal control mechanisms are inertial impaction and direct interception.

g. Fluid-Bed Dry Scrubbers

Fluid-bed dry scrubbers are used in the primary aluminum manufacturing industry to control PM emissions from potroom prebake cells and anode baking furnaces. The dry scrubbing system consists of a fluid-bed reactor with a fabric filter located on top of the reactor.

h. Fuel Switching

Fuel switching to avoid generating PM is a potential process control, but has historically been used to control emissions of NOx and sulfur dioxide (SO_2). With the

passage of the revised national ambient air quality standard covering PM2.5, this technology may become more important in controlling PM emissions from combustion sources (e.g., oil-fired boilers). Industrial, commercial, or institutional (ICI) boilers or process heaters burning coal or oil can reduce PM emissions by switching to natural gas. Switching from coal or oil to natural gas may require retrofit of burners.

i. Miscellaneous Controls

Several PM emission controls are generally considered to be area source controls rather than point source controls, however, they are addressed here because of their widespread use. Two controls used to reduce PM emissions from spray painting in spray paint booths include water curtains and mat or panel filters. Water curtains are water sprays through which paint booth emissions are drawn to remove PM. Alternatively, paint booth emissions are controlled using mat or panel filters. Mat or panel filters are similar to air filters used in residential heating and air conditioning systems.

Wet suppression is a temporary measure for controlling fugitive PM emissions from unpaved surfaces, storage piles, and material handling. Typically, liquid sprays of water, a water solution of a chemical agent (a surfactant or a foaming agent), oil, or micron-sized foam are applied to control emissions. Wet suppression controls emissions by agglomeration (i.e., combining small dust particles with larger particles/aggregates or liquid droplets) to prevent or suppress the PM from leaving the surface and becoming airborne.

2. SOx Control Technologies

Sources of SOx emissions include, in decreasing order of significance, fuel combustion for the generation of electricity, fuel combustion for industrial processes, and emissions from metals production. The different grades of coal and oil combusted to provide heat for boilers or industrial processes all contain some fraction of organically-bound sulfur, as well as, in the case of coal, inorganic sulfur as pyrites. These sources of sulfur form SO_2, and, in lesser amounts, sulfur trioxide when heated in the presence of oxygen.

Many nonferrous metals, such as copper, zinc, and lead, are derived from ores containing sulfur compounds, which, when heated, form SO_2. Coke production and the use of coke in the ferrous metals industry also produce SO_2 emissions. Since SO_2 emissions make up 95 percent or more of the total SOx emissions from combustion sources and SOx emissions are commonly expressed as the SO_2 equivalent, SOx and SO_2 are used interchangeably throughout this report.

There are three main approaches to reducing SOx emissions: pre-combustion methods, control during combustion, and post-combustion methods. In-furnace sorbent addition and flue gas desulfurization are add-on controls which attempt to control emissions during and after combustion, respectively. Fuel switching and fuel cleaning are pre-combustion process controls.

a. Flue Gas Desulfurization (FGD)

The largest category of SO_2 control technologies is FGD, where the SO_2 is captured after formation and removed from the waste gas stream. FGD systems fall into several categories, including dry scrubbing, semi-dry scrubbing, and wet scrubbing. These categories can be further divided into non-regenerable and regenerable systems. Most systems introduce the SO_2-containing waste gas flow to a sorbent, as a solution, slurry, or solid, made up of materials which absorb and react with the SO_2. After the sorbent has absorbed and reacted with the SO_2, the spent reagent is either regenerated or disposed. Some processes are designed to yield a spent reagent that is a desirable product for which there is a market, while others must be disposed. Some regenerable processes concentrate the SO_2 and pass it on to one of several processes which produce liquid SO_2, sulfuric acid, or elemental sulfur.

b. In-Furnace Controls

Several combustion processes are being developed which allow reagents to be introduced or injected directly into the burning fuel. These are known as dry sorbent furnace injection and combustion-zone sorbent addition. With these technologies, the aim is to introduce a material which will react with the SO_2, while avoiding the intense heat of the combustion zone which renders many reactive materials ineffective or less effective. The introduction of the sorbent directly to the combustor allows for longer reaction times between the SO_2 and the reagent, and can reduce the complexity of a sorbent injection system.

c. Fuel Switching

In fuel switching, a low-sulfur fuel is used as a replacement for a fuel with a higher sulfur content. Switching from coal to oil or natural gas for power generation or for certain industrial processes was popular before the early 1970's when economic and legislative restrictions made it a less attractive SO_2-reducing technique. However, co-firing of coal and oil with natural gas has been applied in some situations. High- to low-sulfur coal switching remains popular as an SO_2 reduction method, though it is not applicable in all cases due to low-sulfur coal transportation costs, or combustor inflexibility. In some cases, it has been possible to extend the service life of a high-emitting combustion process by adding just enough low-sulfur coal to the established supply of high-sulfur coal, along with some combustor modifications, to achieve a mandated emissions level.

d. Fuel Cleaning

Fuel cleaning methods have been used to reduce the amount of sulfur in coal before it is combusted in order to lower SO_2 emissions. Sulfur exists in coal in two different forms, inorganic and organic, and each requires a different cleaning technique. Inorganic sulfur in the form of pyrites (compounds of sulfur and iron) is found in most coals, and this is removed mainly by physical means. Often, these processes consist of coal being crushed and screened by density or surface property differentiation using water or air. Chemical cleaning, in which the organic sulfur in coal is removed, is still in the development stage, and has not yet been extensively used in commercial applications.

3. NOx Control Technologies

NOx emissions are generated by stationary sources as a product of combustion or as a stack gas product of a chemical reaction in which NOx assumes the role of either one of the reactants or products. Combustion sources are the predominant NOx generators and, consequently, the majority of the control technologies are designed for combustion sources.

Combustion NOx is formed via three basic mechanisms: thermal NOx, fuel NOx, and prompt NOx. Of the three, combustion NOx control addresses thermal and fuel NOx. Prompt NOx is typically short-lived and requires a very fuel-rich flame. Therefore, prompt NOx controls are not addressed.

The formation of NOx by combustion processes is dependent upon four conditions: the concentration of oxygen at the flame, the peak flame temperature, the residence time of the combustion gases at the flame temperature, and the nitrogen content of the fuel. The control of NOx from combustion processes is divided into three different strategies: modifications of the combustion process or equipment (integrated controls), treatment of flue gas (add-on controls), and fuel modification (process control). Techniques used for NOx control are dependent on the mechanism of NOx formation, the point at which the control strategy is initiated within the combustion process, and the emission source configuration.

a. Combustion (Integrated) Controls

Combustion modifications are proven control techniques that reduce thermal NOx formation by modifying the combustion process to quench combustion gases or to lower oxygen availability and shorten residence times at high temperatures. Several types of combustion modifications used for reducing NOx emissions are low excess air firing, over fire air (OFA), and FGR. Combustion modifications such as these, are intended to reduce the formation of NOx during the combustion process by:

1) restricting the availability of combustion oxygen, and/or

2) quenching the combustion flame temperature.

The restriction of combustion oxygen has the potential of providing a reducing environment during the combustion process and lower peak flame temperature, thereby decreasing the formation of both fuel and thermal NOx. However, the use of aggressive combustion modification, while reducing the formation of NOx, can increase the emissions of carbon monoxide and hydrocarbons. Currently, these modifications are being used on sources such as electric utility boilers, commercial and industrial boilers, and glass melting furnaces.

There are other combustion modifications capable of achieving even greater reductions. These include low NOx-burners for boilers and heaters, and pre-stratified charge systems for reciprocating internal combustion engines. These modifications reduce the formation of NOx by precision control of the combustion process through more advanced combustion technologies and are often designed to provide acceptable performance with low NOx formation. Low NOx burners may incorporate different

combustion control technologies such as flue-gas recirculation and staged combustion as well as improved air/fuel mixing capabilities into one design.

The pre-stratified charge technology introduces an air/fuel charge to the combustion chamber of reciprocating internal combustion engines that is stratified into a large-volume, lean-fuel mixture zone and a small-volume, rich-fuel mixture. Upon compression of the stratified charge, the ignition of the rich-mixture zone provides a hot flame front to ignite the lean-fuel mixture. The resulting combustion process has a reduced peak flame temperature with stable combustion at lean-fuel mixtures approaching the lower flammability limit. Combustion modifications can be used independently or in combination with other control technologies.

b. Exhaust (Add-on) Controls

Add-on control techniques that reduce NOx emissions downstream of the combustion zone are also available. These include selective catalytic reduction, selective non-catalytic reduction, non-selective catalytic reduction, and catalytic oxidation/absorption. In the first three technologies, NOx is reduced to nitrogen and water. For catalytic oxidation/absorption, all of the NOx is oxidized to nitrogen dioxide (NO_2) which is then scrubbed from the exhaust.

c. Process Controls

Different fuels produce different amounts of NOx for a given amount of energy released in the combustion process. This is due to differences in methods of combustion and chemical composition, including fuel nitrogen content. Generally, with respect to NOx and other pollutant emissions, natural gas burns cleaner than petroleum distillate fuels, which burn cleaner than residual fuels, which burn cleaner than solid fossil fuels. Fuel switching can be an effective method of emission reduction for many applications.

4. CO Control Technologies

Good combustion practices on combustion point sources are assumed and are not considered an air pollution control method for this study. Add-on technologies, such as catalytic and non-catalytic oxidizers (see next section) are assumed to control CO emissions with the same efficiency as VOC.

5. TOG and ROG Control Technologies

Most control efficiency data found in the literature are related to the control of VOCs, which are a component of TOG. VOCs include all organic compounds with appreciable vapor pressures. Except for methane, ethane and a number of halogenated compounds identified by EPA as non-reactive, CARB considers all organic gases to be reactive; or ROG. Virtually all of the reviewed literature sources on control equipment simply refers to the group of VOC, ROG, and TOG as VOC. Hence, the control efficiency ranges for TOG and ROG presented in this report are assumed to be equivalent to the VOC ranges reported in the literature. Many VOC species are toxic and are referred to in this report as VOT (described further in the air toxics section below).

In cases where information is available on non-chlorinated VOCs and chlorinated VOCs (CVOCs), this is presented in the description of the specific control equipment presented in Appendix B. In cases where a piece of equipment is capable of destroying both, the control efficiency of the non-chlorinated VOC is typically at the upper end of the range and the CVOC destruction efficiency is at the lower end of the range.

a. Add-on Controls

There are four basic types of add-on controls used to control VOCs: combustion, adsorption, condensation, and absorption. Several new technologies use innovative variations of these basic methods.

Combustion- Combustion, also referred to as oxidation or incineration, is used to destroy VOCs; hence another term for control efficiency by combustion is destruction efficiency. Complete combustion depends on an adequate supply of oxygen, sufficiently high temperature to ignite the waste-fuel mixture, turbulent mixing of the waste-fuel, and sufficient residence time for the reaction to occur.

Devices which use straight combustion to destroy VOC include direct flame thermal oxidizers (incinerators, afterburners) and flares. Because of economics, most combustion devices employ some type of heat recovery to transfer heat from the exhaust gas to the entering waste gas. This is usually in the form of a heat exchanger. Thermal oxidizers so equipped may also be described as "recuperative." Another class of oxidizing equipment known as regenerative thermal oxidizers use a high-density media (e.g., ceramic-packed bed) still hot from a previous cycle to preheat the incoming VOC-laden stream.

Some oxidizers use a catalyst to increase the rate of reaction, reduce the temperature required to produce complete combustion, and reduce the required reactor volume. Most thermal oxidizer designs also have a catalytic counterpart, such as catalytic oxidizers, regenerative catalytic oxidizers, and fluidized bed catalytic oxidizers. Catalytic combustion devices also typically use some type of heat recovery.

Adsorption- Adsorption occurs when organic molecules are captured on the surface of a micro-porous solid such as activated carbon. Adsorption may be physical and/or chemical. Other suitable media (adsorbents) include hydrophobic zeolites, silicates, aluminas, aluminosilicates (molecular sieves), and synthetic resins. These substances have a very porous structure, and with their large exposed surface, can take up appreciable volumes of various gases. The extent of adsorption can be increased further by "activating" the adsorbents in various ways. Activation removes impurities and exposes a larger free surface for potential adsorption. Activated carbon is the most widely used adsorbent.

An adsorption device is typically a two-bed system. VOC-laden air is passed through one bed at a time and treated. Over time, the pore spaces begin to fill. To maintain constant high efficiency, the bed is taken offline and the gas shifted to the other bed before saturation (or "breakthrough") occurs.

Typically, the saturated bed is regenerated, or desorbed with steam. The effluent-steam mixture can be condensed, and, if there is sufficient value, the solvent can be recovered by decanting and/or distillation. The bed may also be desorbed by reducing the

pressure (vacuum desorption). In some cases, the spent adsorbent may be replaced and regenerated offsite.

Condensation- Condensation is the process of converting a gas to a liquid. This is typically accomplished by lowering the temperature. Condensers are simple devices that normally use water for cooling, but may use other heat-exchange media (e.g., chlorinated fluorocarbons). Condensers may be indirect ("surface condensers") or direct contact. In surface condensers, the cooling medium and vapor/condensate are separated by a surface area (e.g., shell and tube). In direct contact condensers, the vapors and cooling medium are intimately mixed and combined. Typical contact condenser types are barometric and jet. The disadvantage of contact condensers is that the condensate cannot be reused and further treatment or separation may be necessary. Most condensers used in air pollution control are surface condensers.

In refrigerated condenser systems, mechanical refrigeration is used for cooling. These systems include a refrigeration unit, a heat exchanger/evaporator, storage for the chilled and defrost brines, and a surface condenser. Cryogenic condensers use the cooling value of liquid nitrogen in a surface 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. Cryogenic condensation is best suited to industries that already use significant quantities of liquid nitrogen in their normal processes for inerting, blanketing, and purging.

Absorption- Absorption is used for VOCs and inorganic gases. It is, however, more commonly employed for inorganic gases [e.g., hydrogen sulfide, ammonia (NH_3), chlorides, and fluorides] than for organic vapors.

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 components 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 and for relatively high VOC concentrations [approximately 1,000 parts per million by volume (ppmv) and higher] of readily water soluble organics (most alcohols, ethylene oxide, organic acids, aldehydes, ketones, amines, and glycols).

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.

New Add-on Control Technologies- The first example of a commonly-employed new technology for VOC control is biofiltration. The mechanism of biofiltration includes a combination of adsorption, absorption, and microbial degradation. Vapor-phase organic

contaminants are passed through a bed of biologically active material, (primarily mixtures based on soil, compost, or peat) and sorb to the material surface, where they are degraded by microorganisms in the material.

Another example of a new VOC technology is ozonation with enhanced carbon adsorption. This technology is an enhanced carbon adsorption system that combines wet scrubbing, carbon adsorption, and ozone reaction to remove organic vapors from an airstream.

The third new VOC technology is ozonation with catalytic oxidation. This gaseous ozonation system employs a catalytic reactor to oxidize VOCs using small amounts of ozone at relatively low temperatures (160 to 220 °F).

Another new technology is flameless thermal oxidation (FTO). FTO is used for destroying VOCs in process and waste stream off-gas treatment and in the treatment of VOCs and CVOCs from off-gases from soil remediation. FTO uses a heated packed-bed reactor filled with inert ceramic pieces maintained at 1,600 to 1,850 °F. The packed bed generates a uniform thermal reaction zone where oxidation of organic compounds occurs and flame propagation is prevented.

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 HEC reactor is a glass tube filled with glass beads. A high-voltage electrode is located along the centerline of the reactor.

Silent Discharge Plasma Technology (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.

In photocatalytic oxidation, VOCs or CVOCs are trapped on the surface of a proprietary catalytic adsorbent. The trapped contaminants are catalytically destroyed (oxidized) by ultra-violet light on the adsorbent, which continuously regenerates the adsorbent.

b. Process Controls

Depending on the process, certain modifications can be effective in controlling VOCs. These include substituting materials to low or no-VOC types, changing the methods by which organic liquids are applied, stored and transferred, and making other operational changes.

6. AIR TOXICS CONTROL TECHNOLOGIES

As previously mentioned, a limited effort was made to include control efficiency data for air toxics. Nearly all of the control technologies in use for control of air toxics were originally designed to control VOC or PM and are described in the appropriate sections above and in Appendix B. To provide the control technology user with a sense of the potential for control of air toxics, a method was outlined in Chapter II to estimate the potential for control of individual toxics using a VOC or PM10 control method.

Researchers included a relatively new technology, carbon injection, in the database that was specifically-designed to control emissions of Hg. This add-on technology is being used in municipal and medical waste incinerators to control both Hg and dioxin/furan emissions (see Appendix B for more details).

REFERENCES

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

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

Bartikowski, 1997. B. Bartikowski, Basys Technologies (800-254-5525), personal communication with E. Albright, E.H. Pechan & Associates, Inc., December 3, 1997.

Belco, 1997. Belco Technologies Corp., personal contact with Tom Walker (973) 884-4700, Parsippany, NJ, December 23, 1997.

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

Carr, 1994. F. Housely Carr, "Scrubbers Going Through a Phase," ENR, Vol. 233, No. 1, July 4, 1994.

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

Clean Air Act Information Network, NOx Controls for Existing Utility Boilers by Bill Neuffer.

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.

Danziger, 1997. Danziger, R; *et al.*; *The SCONOx Catalytic Absorption System for Power Generation: Full-Scale Operational Results;* Presentation; Power-Gen Asia '97; 11 September 1997.

REFERENCES (Continued)

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.

Dennis, 1993. R.A. Dennis, N.W.J. Ford, and M.J. Cooke, "A Guide to Flue Gas Desulphurization for the Industrial Plant Manager," from "Desulfurization 3," Institution of Chemical Engineers Symposium Series No. 131, Warwickshire, UK, 1993.)

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.

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, 1978. U.S. Environmental Protection Agency, *Fugitive Emissions from Integrated Iron and Steel Plants*, EPA-600/2-78-050, Washington, DC, March 1978.

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, 1984. U.S. Environmental Protection Agency, Industrial Environmental Research Laboratory, "The Current Status of Commercial Utility Flue Gas Desulfurization Systems," Research Triangle Park, NC, February 1984.

EPA, 1985. U.S. Environmental Protection Agency, *Flue Gas Conditioning*, EPA-600/7-85-005, NTIS PB85-173912, Research Triangle Park, NC, February 1985.

REFERENCES (Continued)

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, 1991. 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, 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, 1992b. U.S. Environmental Protection Agency, Office of Research and Development, "Facility Pollution Prevention Guide," EPA/600/R-92/088, Washington, DC, May 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, 1992d. 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, 1993a. U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards; "Alternative Control Techniques Document – NOx Emissions from Stationary Gas Turbines," Research Triangle Park, NC, January 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, 1993c. 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, 1993d. U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards; "Alternative Control Techniques Document – NOx Emissions from Process Heaters," Research Triangle Park, NC, September 1993.

REFERENCES (Continued)

EPA, 1994a. 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, 1994b. U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards; "Alternative Control Techniques Document – NOx Emissions from Glass Manufacturing", Research Triangle Park, NC, June 1994.

EPA, 1994c. U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards; "Alternative Control Techniques Document – NOx Emissions from Iron and Steel Mills", Research Triangle Park, NC, September 1994.

EPA, 1994d. U.S. Environmental Protection Agency, National PM Study: OPPE Particulate Programs Implementation Evaluation System, Office of Policy, Planning, and Evaluation, Washington DC, September 1994.

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

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

EPA, 1996b. U.S. Environmental Protection Agency, "Estimating and Controlling Fugitive Lead Emissions from Industrial Sources," EPA-452/R-96-006, Research Triangle Park, NC, May 1996.

EPA, 1997a. U.S. Environmental Protection Agency, "The Emission Reduction And Cost Analysis Model for NOx (ERCAM -- NOx)," September 1997 (Note: This is a draft document).

EPA, 1997b. U.S. Environmental Protection Agency, "Compilation of Air Pollutant Emission Factors, Volume I, Stationary Point and Area Sources," AP-42, Fifth Edition, Research Triangle Park, NC, October 1997.

Friedman, 1981. L.J. Friedman, "Production of Liquid SO_2, Sulfur and Sulfuric Acid," Sulfur Dioxide Control in Pyrometallurgy, edited by T.D. Chatwin and N. Kikumoto, Metallurgical Society of AIME, Warrendale, PA, February 1981.

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.

REFERENCES (Continued)

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.

Hart, 1997. B. Hart, Comprehensive Environmental Solutions, (415-669-1111), personal communication with E. Albright, E.H. Pechan & Associates, Inc., December 3, 1997.

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.

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

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

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

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.

Lurgi, 1997. Personal communication with Ron Triscori (201-967-3191) of Lurgi Corp, Paramus, NJ, December 29, 1997.

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.

REFERENCES (Continued)

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

Pechan, 1988. E.H. Pechan & Associates, Inc., "National Assessment of VOC, CO, and NO_x Controls, Emissions, and Costs," prepared for U.S. Environmental Protection Agency, Office of Policy Planning and Evaluation, Washington, DC, September 1988.

Pechan, 1995. E.H. Pechan & Associates, Inc., "Development of Control Cost Equations for Particulate Matter," Final Report, Prepared for U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Research Triangle Park, NC, September 1995.

Pechan, 1997. E.H. Pechan & Associates, Inc., "Clean Air Act Section 812 Prospective Cost Analysis -- Draft Report," prepared for Industrial Economics, Inc., Cambridge, MA, September 1997.

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

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.

Radcliffe, 1992. Paul Radcliffe, "FGD Economics," EPRI Journal, Vol. 17, No. 6, September 1992.

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.

REFERENCES (Continued)

Roeck, 1996. Douglas R. Roeck and Alfred Sigg, "Carbon Injection Proves Effective in Removing Dioxins," from Environmental Protection, January 1996.

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.

Siebel, 1976. U.S. Department of the Interior, *Dust Control at a Transfer Point Using Foam and Water Sprays*, Publication No. TPR 97, Bureau of Mines, Washington, DC, 1976.

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, 1993. State and Territorial Air Pollution Program Administrators and Association of Local Air Pollution Control Officials, "Meeting the 15-Percent Rate-of-Progress Requirement Under the Clean Air Act: A Menu of Options," September 1993.

REFERENCES (Continued)

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, D.C., 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, "A 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.

REFERENCES (Continued)

WGA, 1988. Western Governors Association, "Western States Acid Deposition Project Phase II: Technical Feasibility and Cost of Obtaining Further Reductions in SO_2 and NOx Emissions from Existing and New Sources, Volume I," Denver, CO, Revised February 1988.

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

Zinc, 1997. John C. Zinc, Ph.D., ED., "Retrofit Burners," Power Engineering, November 1997.

ACRONYMS AND ABBREVIATIONS

AIRS/FS	Aerometric Information Retrieval System/ Facility Subsystem
AWMA	Air and Waste Management Association
BOOS	burner out of service
BTEX	benzene, toluene, ethylbenzene, and total xylenes
°C	degrees Celsius
CARB	California Air Resources Board
CEC	control efficiency code
cfm	cubic feet per minute
cm	centimeter
CO	carbon monoxide
CEC	Control Equipment Code
CTC	Control Technology Code
CVOC	chlorinated volatile organic compound
DESP	dry electrostatic precipitator
DMA	dimethylanaline
DOE	United States Department of Energy
EPA	United States Environmental Protection Agency
EPRI	Electric Power Research Institute
ESP	electrostatic precipitator
°F	degrees Fahrenheit
FBCI	fluidized bed catalytic incineration
FGD	flue gas desulfurization
FGR	flue gas recirculation
FTO	flameless thermal oxidation
GIT	gaseous inorganic toxic
HAPs	hazardous air pollutants
HCl	hydrogen chloride gas or hydrochloric acid
HEC	High Energy Corona
Hg	mercury
hr	hour
ICI	industrial, commercial, and institutional
in	inch
lb	pound
LEA	low excess air
LEC	low emission combustion
LEL	lower explosive limit
LNB	low NOx burners
MEK	methyl ethyl ketone
MMBtu	million British thermal units
NAAQS	National Ambient Air Quality Standards
NEDS	National Emissions Data System

(Continued)

ACRONYMS AND ABBREVIATIONS (Continued)

NH_3	ammonia
NO_2	nitrogen dioxide
NOx	oxides of nitrogen
NSCR	non-selective catalytic reduction
OFA	over fire air
Pechan	E.H. Pechan & Associates, Inc.
PAH	polycyclic aromatic hydrocarbon
PCE	perchloroethylene
PIT	particulate inorganic toxic
PM	particulate matter (total)
PM10	particulate matter less then 10 microns in diameter
PM2.5	particulate matter less then 2.5 microns in diameter
POT	particulate organic toxic
ppm	parts per million
ppmv	parts per million by volume
psi	pounds per square inch
ROG	reactive organic gas
RTO	regenerative thermal oxidation
RCO	regenerative catalytic oxidizer
scfm	standard cubic feet per minute
SCR	selective catalytic reduction
SDPT	Silent Discharge Plasma Technology
SNCR	selective noncatalytic control reduction
SO_2	sulfur dioxide
SOx	oxides of sulfur
STAPPA/ALAPCO	State and Territorial Air Pollution Program Administrators and Association of Local Air Pollution Control Officials
SVE	soil vapor extraction
TCE	trichloroethylene
TNMOG	total nonmethane organic gases
TOG	total organic gases
TSP	total suspended particulate
μm	micrometers
VOC	volatile organic compound
VOL	volatile organic liquid
VOT	volatile organic toxic

APPENDIX A: CONTROL TECHNOLOGY DATABASE

APPENDIX A: CONTROL TECHNOLOGY DATABASE

The control technologies are identified by a three-digit CTC and are ordered by control method and primary pollutant controlled. For reference purposes, the old Control Equipment Code (CEC) from the previous published Turnaround Document (TAD) Manual for each CTC, where applicable. Additional information on the control efficiency ranges, applications, and cost effectiveness is presented in Appendix B. Data on the classification of air toxics (i.e., VOT, POT, PIT, and GIT) are presented in Appendix C.

001 - 399 Add-on Control Technologies

001 - 079	PM, PM10, PM2.5
080 - 159	SOx
160 - 239	NOx
240 - 319	TOG, ROG, VOT
320 - 399	Open

400 - 599 Process Controls

400 - 429	PM, PM10, PM2.5
430 - 449	NOx
450 - 479	TOG, ROG, VOT
480 - 599	Open

600 - 699 Integrated Controls

600 - 679	NOx
680 - 699	Open

700 - 999 Control Combinations

700 - 749	NOx
750 - 949	PM, PM10, PM2.5

Where;

750 - 767	Gravity Collector + Other
768 - 784	Momentum Separator + Other
785 - 802	Centrifugal Collector + Other
803 - 844	Single Cyclone + Other
845 - 870	Multiple Cyclone + Other
871 - 880	ESP + Other
881 - 891	Fabric Filter + Other
892 - 915	Wet scrubber Combinations
916 - 920	Mist Eliminator Combinations
921 - 999	Open

The control efficiencies assigned to the four categories (i.e., VOT, POT, PIT, and GIT) are largely 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.

Users should be extremely careful in assigning control efficiencies using the toxics categorization scheme when dealing with toxics that can take on more than one form (see Appendix C). Also, users should consult the technology descriptions in Appendix B or other literature to ascertain whether the control technology is limited to certain species. For example, the carbon injection control technology is listed as having control efficiencies for POT, PIT, and GIT, however these control efficiencies have only been documented for dioxin/furans (i.e., not all POT) and Hg (i.e., not all PIT or GIT).

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Appendix A: Control Technology Code Numbers and Normal Control Efficiency Range

CTC	CONTROL DEVICE/METHOD	OLD CEC	PM Low	PM High	PM10 Low	PM10 High	PM2.5 Low	PM2.5 High	SOx Low	SOx High	NOx Low	NOx High	CO Low	CO High
	ADD-ON CONTROLS:													
001	Wet Scrubber (General, Not Classified)	001	55	> 99.9	55	> 99.9	25.0	97.0	50	> 99.0				
002	Electrostatic Precipitator (Dry)	010	90	> 99.9	85	99.5	80.0	> 99.0						
003	Electrostatic Precipitator (Dry) with Flue Gas Conditioning	NEW	90	> 99.9	85	99.5	80.0	> 99.0						
004	Electrostatic Precipitator (Wet)	NEW	80	> 99.9	75	99.5	70.0	> 99.0						
005	Fabric Filter (Pulse-jet, Reverse-air, Mechanical Shaker)	016	90	> 99.9	85	> 99.9	80.0	99.9	15	30.0				
006	Venturi or Orifice Scrubber	053	90	> 99.0	70	> 99.0	25.0	99.0	80	> 99.0				
007	Single Cyclone (conventional)	075	70	90.0	30	90.0	0.0	40.0						
008	Single Cyclone (high efficiency)	075	80	99.0	60	95.0	20.0	70.0						
009	Single Cyclone (high throughput)	075	80	99.0	10	40.0	0.0	10.0						
010	Multiple Cyclone w/o Fly Ash Reinjection	076	80	99.0	50	95.0	20.0	70.0						
011	Multiple Cyclone w/ Fly Ash Reinjection	077	70	99.0	35	85.0	20.0	60.0						
012	Mist Eliminator - Blade Type	014	80	98.0	80	98.0	50.0	70.0						
013	Mist Eliminator - Mesh-Type	015	95	> 99.0	95	> 99.0	90.0	99.0						
014	Spray Chamber Wet Scrubber (Spray Tower, Mist Scrubber, Cyclonic Spray Tower, Vane-type Cyclonic Tower)	052	70	> 99.5	70	99.0	25.0	97.0	80	> 99.0				
015	Gravity Collector (Settling Chamber)	004, 005, 006	10	99.0										

Appendix A: Control Technology Code Numbers and Normal Control Efficiency Range

CTC	CONTROL DEVICE/METHOD	OLD CEC	TOG Low	TOG High	ROG Low	ROG High	VOT Low	VOT High	POT Low	POT High	PIT Low	PIT High	GIT Low	GIT High
	ADD-ON CONTROLS:													
001	Wet Scrubber (General, Not Classified)	001							55	> 99.9	55	> 99.9		
002	Electrostatic Precipitator (Dry)	010							85	99.5	85	99.5		
003	Electrostatic Precipitator (Dry) with Flue Gas Conditioning	NEW							85	99.5	85	99.5		
004	Electrostatic Precipitator (Wet)	NEW	50.0	70.0	50.0	70.0	50.0	70.0	75	99.5	75	99.5		
005	Fabric Filter (Pulse-jet, Reverse-air, Mechanical Shaker)	016							85	> 99.9	85	> 99.9		
006	Venturi or Orifice Scrubber	053							70	> 99.0	70	> 99.0		
007	Single Cyclone (conventional)	075							30	90.0	30	90.0		
008	Single Cyclone (high efficiency)	075							60	95.0	60	95.0		
009	Single Cyclone (high throughput)	075							10	40.0	10	40.0		
010	Multiple Cyclone w/o Fly Ash Reinjection	076							50	95.0	50	95.0		
011	Multiple Cyclone w/ Fly Ash Reinjection	077							35	85.0	35	85.0		
012	Mist Eliminator - Blade Type	014							80	98.0	80	98.0		
013	Mist Eliminator - Mesh-Type	015							95	> 99.0	95	> 99.0		
014	Spray Chamber Wet Scrubber (Spray Tower, Mist Scrubber, Cyclonic Spray Tower, Vane-type Cyclonic Tower)	052	50	95.0	50	95.0	50	95.0	70	99.0	70	99.0	85	> 99.0
015	Gravity Collector (Settling Chamber)	004, 005, 006												

Appendix A: Control Technology Code Numbers and Normal Control Efficiency Range

CTC	CONTROL DEVICE/METHOD	OLD CEC	PM Low	PM High	PM10 Low	PM10 High	PM2.5 Low	PM2.5 High	SOx Low	SOx High	NOx Low	NOx High	CO Low	CO High
016	Centrifugal Collector (Mechanically-aided Separator or Dry Dynamic Separator)	007, 008, 009, 056	30	99.0	0	10.0	0.0	5.0						
017	Momentum Separator	NEW	30	99.0	0	10.0	0.0	5.0						
018	Tray-Type Scrubber [Impingement Plate, Perforated Plate, Horizontal Impingement-Plate (Baffle)]	055	55	99.0	55	99.0	25.0	97.0	80	> 99.0				
019	Mat or Panel Filter	058	10	98.0	10	90.0								
020	Gravel Bed Filter	063	90	> 99.5	85	99.0	80.0	99.0						
021	Gravel Bed Moving Filter	063	80	95.0	70	90.0								
022	Gravel Bed Moving Filter - Electrostatically Augmented	NEW	80	> 99.0	70	95.0								
023	Mechanically-Aided Scrubber	001	70	> 99.0	70	99.0	25.0	97.0						
024	Condensation Scrubber	001	90	> 99.0	70	> 99.0	25.0	99.0						
025	Charged Scrubber	001	90	> 99.0	70	> 99.0	25.0	99.0						
026	Packed-Bed Scrubber (Fiber-Bed, Moving-Bed, Cross-Flow, Grid-Packed)	001	85	> 99.0	85	99.0	25.0	97.0						
027	Fluid-Bed Dry Scrubber	071	90	> 99.9	85	> 99.9	80.0	99.9						
028	Dust Suppression by Water Sprays	061	30	99.0	30	95.0	30	90.0						
029	Dust Suppression by Chemical Stabilizers or Wetting Agents	062	30	99.0	30	95.0	30	90.0						
030	Water Curtain	086	10	95.0										
031	Chemical Fume Suppressants for Electroplating and Anodizing Tanks	NEW	99	99.9	99	99.9	95.0	99.0						

Appendix A: Control Technology Code Numbers and Normal Control Efficiency Range

			TOG		ROG		VOT		POT		PIT		GIT	
CTC	CONTROL DEVICE/METHOD	OLD CEC	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
016	Centrifugal Collector (Mechanically-aided Separator or Dry Dynamic Separator)	007, 008, 009, 056							0	10.0	0	10.0		
017	Momentum Separator	NEW							0	10.0	0	10.0		
018	Tray-Type Scrubber [Impingement Plate, Perforated Plate, Horizontal Impingement-Plate (Baffle)]	055							55	99.0	55	99.0		
019	Mat or Panel Filter	058							10	90.0	10	90.0		
020	Gravel Bed Filter	063							85	99.0	85	99.0		
021	Gravel Bed Moving Filter	063							70	90.0	70	90.0		
022	Gravel Bed Moving Filter - Electrostatically Augmented	NEW							70	95.0	70	95.0		
023	Mechanically-Aided Scrubber	001							70	99.0	70	99.0		
024	Condensation Scrubber	001							70	> 99.0	70	> 99.0		
025	Charged Scrubber	001							70	> 99.0	70	> 99.0		
026	Packed-Bed Scrubber (Fiber-Bed, Moving-Bed, Cross-Flow, Grid-Packed)	001							85	99.0	85	99.0		
027	Fluid-Bed Dry Scrubber	071	80	90.0	80	90.0	80	90.0	85	> 99.9	85	> 99.9		
028	Dust Suppression by Water Sprays	061												
029	Dust Suppression by Chemical Stabilizers or Wetting Agents	062												
030	Water Curtain	086												
031	Chemical Fume Suppressants for Electroplating and Anodizing Tanks	NEW									99	99.9		

Appendix A: Control Technology Code Numbers and Normal Control Efficiency Range

CTC	CONTROL DEVICE/METHOD	OLD CEC	PM Low	PM High	PM10 Low	PM10 High	PM2.5 Low	PM2.5 High	SOx Low	SOx High	NOx Low	NOx High	CO Low	CO High
032	Plastic Balls for Electroplating Tanks	NEW	50	80.0	50	80.0	20.0	50.0						
080	Gas Scrubber (general, not classified)	013							20	> 99.0				
081	Wellman-Lord/Sodium Sulfite Scrubbing	034							90	> 99.0				
082	Magnesium Oxide Scrubbing	035							85	> 99.0				
083	Dual Alkali Scrubbing	036							85	95.0				
084	Citrate Process Scrubbing	037							90	99.0				
085	Ammonia Scrubbing	038							90	95.0				
086	Catalytic Oxidation - Flue Gas Desulfurization	039							90	99.0				
087	Dry Sorbent Duct Injection	041							50	80.0				
088	Circulating Dry Scrubbing	041							70	90.0				
089	Wet Sorbent Injection/Spray Drying	042							30	90.0				
090	Sulfuric Acid Plant - Contact Process	043							95	98.0				
091	Sulfuric Acid Plant - Double Contact Process	044							98	> 99.0				
092	Claus Process Sulfur Plant, without Tail Gas Treatment	045							95	99.0				
093	Claus Process Sulfur Plant, with Tail Gas Treatment	045							98	> 99.0				
094	Adsorption: various adsorbents, including activated carbon, zeolites, molecular sieves, silicates, aluminas, and synthetic resins	048							70	80.0				
095	Adsorption: copper oxide	NEW							80	90.0				

Appendix A: Control Technology Code Numbers and Normal Control Efficiency Range

CTC	CONTROL DEVICE/METHOD	OLD CEC	TOG Low	TOG High	ROG Low	ROG High	VOT Low	VOT High	POT Low	POT High	PIT Low	PIT High	GIT Low	GIT High
032	Plastic Balls for Electroplating Tanks	NEW									50	80.0		
080	Gas Scrubber (general, not classified)	013											85	> 99.0
081	Wellman-Lord/Sodium Sulfite Scrubbing	034												
082	Magnesium Oxide Scrubbing	035												
083	Dual Alkali Scrubbing	036												
084	Citrate Process Scrubbing	037												
085	Ammonia Scrubbing	038												
086	Catalytic Oxidation - Flue Gas Desulfurization	039												
087	Dry Sorbent Duct Injection	041												
088	Circulating Dry Scrubbing	041												
089	Wet Sorbent Injection/Spray Drying	042												
090	Sulfuric Acid Plant - Contact Process	043												
091	Sulfuric Acid Plant - Double Contact Process	044												
092	Claus Process Sulfur Plant, without Tail Gas Treatment	045												
093	Claus Process Sulfur Plant, with Tail Gas Treatment	045												
094	Adsorption: various adsorbents, including activated carbon, zeolites, molecular sieves, silicates, aluminas, and synthetic resins	048	90	> 99.0	90	> 99.0	90	> 99.0					90	> 99.0
095	Adsorption: copper oxide	NEW												

Appendix A: Control Technology Code Numbers and Normal Control Efficiency Range

CTC	CONTROL DEVICE/METHOD	OLD CEC	PM Low	PM High	PM10 Low	PM10 High	PM2.5 Low	PM2.5 High	SOx Low	SOx High	NOx Low	NOx High	CO Low	CO High
096	Packed Column - Gas Absorption	050							80	> 99.0				
097	Tray-Type Gas Absorption Column (NOx data for adipic and nitric acid process)	051							80	> 99.0	85	97.0		
098	Wet Lime/Limestone Slurry Scrubbing	067							60	98.0				
099	Alkaline Fly Ash Scrubbing	068							50	95.0				
100	Sodium Carbonate Scrubbing	069							80	98.0				
101	Sodium Hydroxide Scrubbing	070							70	95.0				
102	Dimethylaniline Scrubbing	NEW							95	99.0				
103	Hydrogen Peroxide Scrubbing	NEW							90	99.0				
104	Seawater Scrubbing	001							85	98.0				
105	Dry Sorbent Furnace Injection without Duct Humidification	041							20	70.0				
106	Dry Sorbent Furnace Injection with Duct Humidification	041							40	90.0				
107	Combustion-Zone Sorbent Addition	041							15	90.0				
160	Selective Non-Catalytic Reduction, Annealing Furnace	032									25	60.0		
161	Selective Non-Catalytic Reduction, Glass Furnace	032									30	60.0		
162	Selective Non-Catalytic Reduction, Industrial & Commercial Boiler, Gas	032									30	60.0		
163	Selective Non-Catalytic Reduction, Industrial & Commercial Boiler, Coal/Oil	032									30	70.0		
164	Selective Non-Catalytic Reduction, Cement Kiln, Precalciner	032									30	70.0		

Appendix A: Control Technology Code Numbers and Normal Control Efficiency Range

CTC	CONTROL DEVICE/METHOD	OLD CEC	TOG Low	TOG High	ROG Low	ROG High	VOT Low	VOT High	POT Low	POT High	PIT Low	PIT High	GIT Low	GIT High
096	Packed Column - Gas Absorption	050	70	> 99.0	70	> 99.0	70	> 99.0					85	> 99.0
097	Tray-Type Gas Absorption Column (NOx data for adipic and nitric acid process)	051	70	> 99.0	70	> 99.0	70	> 99.0					85	> 99.0
098	Wet Lime/Limestone Slurry Scrubbing	067												
099	Alkaline Fly Ash Scrubbing	068												
100	Sodium Carbonate Scrubbing	069												
101	Sodium Hydroxide Scrubbing	070												
102	Dimethylaniline Scrubbing	NEW												
103	Hydrogen Peroxide Scrubbing	NEW												
104	Seawater Scrubbing	001												
105	Dry Sorbent Furnace Injection without Duct Humidification	041												
106	Dry Sorbent Furnace Injection with Duct Humidification	041												
107	Combustion-Zone Sorbent Addition	041												
160	Selective Non-Catalytic Reduction, Annealing Furnace	032												
161	Selective Non-Catalytic Reduction, Glass Furnace	032												
162	Selective Non-Catalytic Reduction, Industrial & Commercial Boiler, Gas	032												
163	Selective Non-Catalytic Reduction, Industrial & Commercial Boiler, Coal/Oil	032												
164	Selective Non-Catalytic Reduction, Cement Kiln, Precalciner	032												

Appendix A: Control Technology Code Numbers and Normal Control Efficiency Range

CTC	CONTROL DEVICE/METHOD	OLD CEC	PM Low	PM High	PM10 Low	PM10 High	PM2.5 Low	PM2.5 High	SOx Low	SOx High	NOx Low	NOx High	CO Low	CO High
165	Selective Non-Catalytic Reduction, Process Heaters, Gas	032									20	50.0		
166	Selective Non-Catalytic Reduction, Process Heaters, Residual/Distillate Oil	032									30	60.0		
167	Selective Non-Catalytic Reduction, Utility Boiler, Coal	032									30	60.0		
168	Selective Non-Catalytic Reduction, Utility Boiler, Oil or Gas	032									35	50.0		
169	Selective Catalytic Reduction, Glass Furnace	065									70	80.0		
170	Selective Catalytic Reduction, Annealing Furnace	065									70	90.0		
171	Selective Catalytic Reduction, Industrial & Commercial Boiler	065									80	90.0		
172	Selective Catalytic Reduction, Utility Boiler, Oil or Gas	065									50	95.0		
173	Selective Catalytic Reduction, Lean Burn Diesel or Dual Fuels	065									80	90.0		
174	Selective Catalytic Reduction, Cement Kiln	065									80	90.0		
175	Selective Catalytic Reduction, Nitric Acid Process	065									85	95.0		
176	Selective Catalytic Reduction, Process Heaters, Residual Oil	065									75	90.0		
177	Selective Catalytic Reduction, Process Heaters, Distillate Oil	065									80	90.0		
178	Selective Catalytic Reduction, Process Heaters, Gas	065									80	90.0		
179	Selective Catalytic Reduction, Utility Boiler, Coal	065									60	90.0		
180	Non-Selective Catalytic Reduction, Rich Burn Gas	065									90	95.0		
181	Non-Selective Catalytic Reduction, Nitric Acid Process	065									95	> 99.0		
182	Non-Selective Catalytic Oxidation and Absorption, Gas Turbine	065									99	> 99.0		

Appendix A: Control Technology Code Numbers and Normal Control Efficiency Range

CTC	CONTROL DEVICE/METHOD	OLD CEC	TOG Low	TOG High	ROG Low	ROG High	VOT Low	VOT High	POT Low	POT High	PIT Low	PIT High	GIT Low	GIT High
165	Selective Non-Catalytic Reduction, Process Heaters, Gas	032												
166	Selective Non-Catalytic Reduction, Process Heaters, Residual/Distillate Oil	032												
167	Selective Non-Catalytic Reduction, Utility Boiler, Coal	032												
168	Selective Non-Catalytic Reduction, Utility Boiler, Oil or Gas	032												
169	Selective Catalytic Reduction, Glass Furnace	065												
170	Selective Catalytic Reduction, Annealing Furnace	065												
171	Selective Catalytic Reduction, Industrial & Commercial Boiler	065												
172	Selective Catalytic Reduction, Utility Boiler, Oil or Gas	065												
173	Selective Catalytic Reduction, Lean Burn Diesel or Dual Fuels	065												
174	Selective Catalytic Reduction, Cement Kiln	065												
175	Selective Catalytic Reduction, Nitric Acid Process	065												
176	Selective Catalytic Reduction, Process Heaters, Residual Oil	065												
177	Selective Catalytic Reduction, Process Heaters, Distillate Oil	065												
178	Selective Catalytic Reduction, Process Heaters, Gas	065												
179	Selective Catalytic Reduction, Utility Boiler, Coal	065												
180	Non-Selective Catalytic Reduction, Rich Burn Gas	065												
181	Non-Selective Catalytic Reduction, Nitric Acid Process	065												
182	Non-Selective Catalytic Oxidation and Absorption, Gas Turbine	065												

Appendix A: Control Technology Code Numbers and Normal Control Efficiency Range

CTC	CONTROL DEVICE/METHOD	OLD CEC	PM Low	PM High	PM10 Low	PM10 High	PM2.5 Low	PM2.5 High	SOx Low	SOx High	NOx Low	NOx High	CO Low	CO High
183	Thermal Reduction, Adipic Acid	NEW									70	95.0		
240	Catalytic Oxidizer	019 020	25	> 99.0	25	> 99.0							90	99.0
241	Direct Flame Thermal Oxidizer	021 022	25	> 99.0	25	> 99.0							95	> 99.0
242	Flaring	023	25	98.0	25	98.0							98	> 99.0
243	Regenerative Thermal Oxidizer	NEW	25	> 99.0	25	> 99.0							95	> 99.0
244	Regenerative Catalytic Oxidizer	NEW	25	> 99.0	25	> 99.0							90	99.0
245	Fluidized Bed Catalytic Incineration	NEW	25	> 99.0	25	> 99.0							70	> 99.0
246	Flameless Thermal Oxidation	NEW	25	> 99.0	25	> 99.0							99	> 99.0
247	High Energy Corona	NEW											90	> 99.0
248	Silent Discharge Plasma Technology	NEW											95	99.0
249	Photocatalytic Oxidation	NEW											95	> 99.0
250	Ozonation - Catalytic Oxidation	082												
251	Ozonation - Enhanced Carbon Adsorption	082												
252	Biofiltration	NEW												
253	Cryogenic Condensation	NEW												
254	Water blanket	NEW												
255	Vapor Recovery System (Stage I) - Bulk Terminals	047												
256	Vapor Recovery System (Stage I) - Bulk Plants	047												

Appendix A: Control Technology Code Numbers and Normal Control Efficiency Range

			TOG		ROG		VOT		POT		PIT		GIT	
CTC	CONTROL DEVICE/METHOD	OLD CEC	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
183	Thermal Reduction, Adipic Acid	NEW												
240	Catalytic Oxidizer	019 020	90	99.0	90	99.0	90	99.0	90	99.0				
241	Direct Flame Thermal Oxidizer	021 022	95	> 99.0	95	> 99.0	95	> 99.0	95	> 99.0				
242	Flaring	023	98	> 99.0	98	> 99.0	98	> 99.0	98	> 99.0				
243	Regenerative Thermal Oxidizer	NEW	95	> 99.0	95	> 99.0	95	> 99.0	95	> 99.0				
244	Regenerative Catalytic Oxidizer	NEW	90	99.0	90	99.0	90	99.0	90	99.0				
245	Fluidized Bed Catalytic Incineration	NEW	70	> 99.0	70	> 99.0	70	> 99.0	70	> 99.0				
246	Flameless Thermal Oxidation	NEW	99	> 99.0	99	> 99.0	99	> 99.0	99	> 99.0				
247	High Energy Corona	NEW	90	> 99.0	90	> 99.0	90	> 99.0						
248	Silent Discharge Plasma Technology	NEW	95	99.0	95	99.0	95	99.0						
249	Photocatalytic Oxidation	NEW	95	> 99.0	95	> 99.0	95	> 99.0						
250	Ozonation - Catalytic Oxidation	082	95	> 99.0	95	> 99.0	95	> 99.0						
251	Ozonation - Enhanced Carbon Adsorption	082	95	> 99.0	95	> 99.0	95	> 99.0						
252	Biofiltration	NEW	75	99.0	75	99.0	75	99.0						
253	Cryogenic Condensation	NEW	95	> 99.0	95	> 99.0	95	> 99.0						
254	Water blanket	NEW	90	> 99.0	90	> 99.0	90	> 99.0						
255	Vapor Recovery System (Stage I) - Bulk Terminals	047	95	99.0	95	99.0	95	99.0						
256	Vapor Recovery System (Stage I) - Bulk Plants	047	90	95.0	90	95.0	90	95.0						

Appendix A: Control Technology Code Numbers and Normal Control Efficiency Range

CTC	CONTROL DEVICE/METHOD	OLD CEC	PM Low	PM High	PM10 Low	PM10 High	PM2.5 Low	PM2.5 High	SOx Low	SOx High	NOx Low	NOx High	CO Low	CO High
257	Tube and Shell Condenser	072												
258	Refrigerated Condenser	073												
259	Contact Condensers	074												
320	Carbon Injection	NEW												
399	Miscellaneous Add-on Control Devices	099	-	-	-	-	-	-	-	-	-	-	-	-
	PROCESS CONTROLS:													
400	Fuel Switching: High Sulfur Coal to Low Sulfur Coal	NEW							50	90.0				
401	Fuel Switching: Coal to No. 4 and Distillate Oil	NEW	90	> 99.0	80	99.0	70.0	99.0	0	90.0	0	90.0	0	90.0
402	Fuel Switching: Coal to Natural Gas	NEW	98	> 99.0	98	> 99.0	98.0	> 99.0	98	> 99.0	30	90.0	30	98.0
403	Fuel Switching: Residual Oil to Distillate Oil	NEW	60	> 99.0	80	> 99.0	80.0	> 99.0	60	98.0	0	70.0	0	80.0
404	Fuel Switching: Oil to Natural Gas	NEW	90	> 99.0	80	> 99.0	50.0	> 99.0	98	> 99.0	30	80.0	30	90.0
405	Coal Cleaning	NEW							10	40.0				
431	Electric Boost, Glass Manufacturing	NEW									10	25.0		
432	Cullet Preheat, Glass Manufacturing	NEW									5	25.0		
450	Inert Gas Blanketing	087												
451	Conversion to Variable Vapor Space Tank	090												
452	Conversion to Floating Roof Tank	091												
453	Conversion to Pressurized Tank	092												

Appendix A: Control Technology Code Numbers and Normal Control Efficiency Range

CTC	CONTROL DEVICE/METHOD	OLD CEC	TOG Low	TOG High	ROG Low	ROG High	VOT Low	VOT High	POT Low	POT High	PIT Low	PIT High	GIT Low	GIT High
257	Tube and Shell Condenser	072	50	90.0	50	90.0	50	90.0						
258	Refrigerated Condenser	073	50	95.0	50	95.0	50	95.0						
259	Contact Condensers	074	50	90.0	50	90.0	50	90.0						
320	Carbon Injection	NEW					95	> 99.0	95	> 99.0			95	> 99.0
399	Miscellaneous Add-on Control Devices	099	-	-	-	-	-	-	-	-	-	-	-	-
	PROCESS CONTROLS:													
400	Fuel Switching: High Sulfur Coal to Low Sulfur Coal	NEW												
401	Fuel Switching: Coal to No. 4 and Distillate Oil	NEW							80	99.0	80	99.0		
402	Fuel Switching: Coal to Natural Gas	NEW							98	> 99.0	98	> 99.0		
403	Fuel Switching: Residual Oil to Distillate Oil	NEW							80	> 99.0	80	> 99.0		
404	Fuel Switching: Oil to Natural Gas	NEW							80	> 99.0	80	> 99.0		
405	Coal Cleaning	NEW												
431	Electric Boost, Glass Manufacturing	NEW												
432	Cullet Preheat, Glass Manufacturing	NEW												
450	Inert Gas Blanketing	087	90	98.0	90	98.0	90	98.0						
451	Conversion to Variable Vapor Space Tank	090	10	> 99.0	10	> 99.0	10	> 99.0						
452	Conversion to Floating Roof Tank	091	60	99.0	60	99.0	60	99.0						
453	Conversion to Pressurized Tank	092	95	> 99.0	95	> 99.0	95	> 99.0						

Appendix A: Control Technology Code Numbers and Normal Control Efficiency Range

CTC	CONTROL DEVICE/METHOD	OLD CEC	PM Low	PM High	PM10 Low	PM10 High	PM2.5 Low	PM2.5 High	SOx Low	SOx High	NOx Low	NOx High	CO Low	CO High
454	Submerged/Bottom Filling	089 093												
455	Underground Tank	094												
456	White Paint	095												
457	Process Change	046							10	90.0				
599	Miscellaneous Process Controls	099	-	-	-	-	-	-	-	-	-	-	-	-
	INTEGRATED CONTROLS:													
600	Low NOx Burners, Process Heaters, Gas	024									30	60.0		
601	Low NOx Burners, Process Heaters, Residual Oil	024									30	60.0		
602	Low NOx Burners, Utility Boiler, Coal	024									20	50.0		
603	Low NOx Burners, Utility Boiler, Oil or Gas	024									30	50.0		
604	Low NOx Burners, Cement Kiln, Mid-kiln firing	024									20	40.0		
605	Dry Low NOx Combustor, Gas Turbine	024									60	90.0		
606	Staged Combustion	025									20	60.0		
607	Staged Combustion, Cement Kiln	025									30	45.0		
608	Flue Gas Recirculation	026									20	70.0		
609	Flue Gas Recirculation, Industrial & Commercial Boiler, Coal	026									20	45.0		
610	Flue Gas Recirculation, Industrial & Commercial Boiler, Oil	026									15	30.0		
611	Flue Gas Recirculation, Industrial & Commercial Boiler, Gas	026									50	65.0		

Appendix A: Control Technology Code Numbers and Normal Control Efficiency Range

CTC	CONTROL DEVICE/METHOD	OLD CEC	TOG Low	TOG High	ROG Low	ROG High	VOT Low	VOT High	POT Low	POT High	PIT Low	PIT High	GIT Low	GIT High
454	Submerged/Bottom Filling	089 093	10	60.0	10	60.0	10	60.0						
455	Underground Tank	094	98	> 99.0	98	> 99.0	98	> 99.0						
456	White Paint	095	0	30.0	0	30.0	0	30.0						
457	Process Change	046	10	> 99.0	10	> 99.0	10	> 99.0						
599	Miscellaneous Process Controls	099	-	-	-	-	-	-	-	-	-	-	-	-
	INTEGRATED CONTROLS:													
600	Low NOx Burners, Process Heaters, Gas	024												
601	Low NOx Burners, Process Heaters, Residual Oil	024												
602	Low NOx Burners, Utility Boiler, Coal	024												
603	Low NOx Burners, Utility Boiler, Oil or Gas	024												
604	Low NOx Burners, Cement Kiln, Mid-kiln firing	024												
605	Dry Low NOx Combustor, Gas Turbine	024												
606	Staged Combustion	025												
607	Staged Combustion, Cement Kiln	025												
608	Flue Gas Recirculation	026												
609	Flue Gas Recirculation, Industrial & Commercial Boiler, Coal	026												
610	Flue Gas Recirculation, Industrial & Commercial Boiler, Oil	026												
611	Flue Gas Recirculation, Industrial & Commercial Boiler, Gas	026												

Appendix A: Control Technology Code Numbers and Normal Control Efficiency Range

CTC	CONTROL DEVICE/METHOD	OLD CEC	PM Low	PM High	PM10 Low	PM10 High	PM2.5 Low	PM2.5 High	SOx Low	SOx High	NOx Low	NOx High	CO Low	CO High
612	Flue Gas Recirculation, Process Heaters, Oil	026									30	50.0		
613	Flue Gas Recirculation, Process Heaters, Gas	026									50	60.0		
614	Flue Gas Recirculation, Utility Boiler, Coal	026									20	45.0		
615	Flue Gas Recirculation, Utility Boiler, Oil or Gas	026									40	50.0		
616	Low Excess Air, Steel Reheat Furnace	029									10	15.0		
617	Low Excess Air, Industrial & Commercial Boiler, Oil	029									5	25.0		
618	Low Excess Air, Industrial & Commercial Boiler, Coal	029									5	30.0		
619	Low Excess Air, Industrial & Commercial Boiler, Gas	029									5	35.0		
620	Low Excess Air, Process Heaters, Oil	029									5	20.0		
621	Low Excess Air, Process Heaters, Gas	029									5	20.0		
622	Low Excess Air, Utility Boiler, Coal	029									10	20.0		
623	Low Excess Air, Utility Boiler, Oil or Gas	029									10	25.0		
624	Over Fire Air, Industrial & Commercial Boiler, Coal	033									15	30.0		
625	Over Fire Air, Industrial & Commercial Boiler, Gas or Oil	033									20	40.0		
626	Over Fire Air, Utility Boiler, Oil or Gas	033									15	45.0		
627	Over Fire Air, Utility Boiler, Coal	033									15	30.0		
628	Low Emission Combustion, Lean Burn Dual Fuels	NEW									60	80.0		
629	Low Emission Combustion, Rich Burn Gas	NEW									70	90.0		

Appendix A: Control Technology Code Numbers and Normal Control Efficiency Range

			TOG		ROG		VOT		POT		PIT		GIT	
CTC	CONTROL DEVICE/METHOD	OLD CEC	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
612	Flue Gas Recirculation, Process Heaters, Oil	026												
613	Flue Gas Recirculation, Process Heaters, Gas	026												
614	Flue Gas Recirculation, Utility Boiler, Coal	026												
615	Flue Gas Recirculation, Utility Boiler, Oil or Gas	026												
616	Low Excess Air, Steel Reheat Furnace	029												
617	Low Excess Air, Industrial & Commercial Boiler, Oil	029												
618	Low Excess Air, Industrial & Commercial Boiler, Coal	029												
619	Low Excess Air, Industrial & Commercial Boiler, Gas	029												
620	Low Excess Air, Process Heaters, Oil	029												
621	Low Excess Air, Process Heaters, Gas	029												
622	Low Excess Air, Utility Boiler, Coal	029												
623	Low Excess Air, Utility Boiler, Oil or Gas	029												
624	Over Fire Air, Industrial & Commercial Boiler, Coal	033												
625	Over Fire Air, Industrial & Commercial Boiler, Gas or Oil	033												
626	Over Fire Air, Utility Boiler, Oil or Gas	033												
627	Over Fire Air, Utility Boiler, Coal	033												
628	Low Emission Combustion, Lean Burn Dual Fuels	NEW												
629	Low Emission Combustion, Rich Burn Gas	NEW												

Appendix A: Control Technology Code Numbers and Normal Control Efficiency Range

CTC	CONTROL DEVICE/METHOD	OLD CEC	PM Low	PM High	PM10 Low	PM10 High	PM2.5 Low	PM2.5 High	SOx Low	SOx High	NOx Low	NOx High	CO Low	CO High
630	Low Emission Combustion, Lean Burn Gas	NEW									80	90.0		
631	Ignition Timing Retard, Rich Burn Gas	NEW									0	40.0		
632	Ignition Timing Retard, Lean Burn Gas	NEW									0	20.0		
633	Ignition Timing Retard, Lean Burn Diesel	033									20	30.0		
634	Ignition Timing Retard, Lean Burn Dual Fuels	033									20	30.0		
635	Air-Fuel Ratio Adjustment, Internal Combustion Engines	033									5	40.0		
636	Prestratified Charge Combustion	NEW									80	90.0		
637	Burner Out of Service, Utility Boiler, Coal	NEW									10	20.0		
638	Burner Out of Service, Utility Boiler, Oil or Gas	NEW									15	35.0		
639	Burner Out of Service, Industrial & Commercial Boiler, Coal, Oil or Gas	NEW									10	30.0		
640	Natural Gas Reburn, Industrial & Commercial Boiler, Coal	NEW									25	60.0		
641	Natural Gas Reburn, Industrial & Commercial Boiler, Oil	NEW									15	35.0		
642	Natural Gas Reburn, Utility Boiler, Coal	NEW									25	60.0		
643	Oxygen Firing, Glass Furnace	NEW									80	90.0		
644	Radiant Burners, Process Heaters, Gas	NEW									80	90.0		
645	Radiant Burners, Industrial & Commercial Boiler, Gas	NEW									70	90.0		
646	Water/Steam Injection, Oil, Industrial & Commercial Boiler	028									15	35.0		
647	Water/Steam Injection, Gas, Industrial & Commercial Boiler	028									25	50.0		

Appendix A: Control Technology Code Numbers and Normal Control Efficiency Range

			TOG		ROG		VOT		POT		PIT		GIT	
CTC	CONTROL DEVICE/METHOD	OLD CEC	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
630	Low Emission Combustion, Lean Burn Gas	NEW												
631	Ignition Timing Retard, Rich Burn Gas	NEW												
632	Ignition Timing Retard, Lean Burn Gas	NEW												
633	Ignition Timing Retard, Lean Burn Diesel	033												
634	Ignition Timing Retard, Lean Burn Dual Fuels	033												
635	Air-Fuel Ratio Adjustment, Internal Combustion Engines	033												
636	Prestratified Charge Combustion	NEW												
637	Burner Out of Service, Utility Boiler, Coal	NEW												
638	Burner Out of Service, Utility Boiler, Oil or Gas	NEW												
639	Burner Out of Service, Industrial & Commercial Boiler, Coal, Oil or Gas	NEW												
640	Natural Gas Reburn, Industrial & Commercial Boiler, Coal	NEW												
641	Natural Gas Reburn, Industrial & Commercial Boiler, Oil	NEW												
642	Natural Gas Reburn, Utility Boiler, Coal	NEW												
643	Oxygen Firing, Glass Furnace	NEW												
644	Radiant Burners, Process Heaters, Gas	NEW												
645	Radiant Burners, Industrial & Commercial Boiler, Gas	NEW												
646	Water/Steam Injection, Oil, Industrial & Commercial Boiler	028												
647	Water/Steam Injection, Gas, Industrial & Commercial Boiler	028												

Appendix A: Control Technology Code Numbers and Normal Control Efficiency Range

CTC	CONTROL DEVICE/METHOD	OLD CEC	PM Low	PM High	PM10 Low	PM10 High	PM2.5 Low	PM2.5 High	SOx Low	SOx High	NOx Low	NOx High	CO Low	CO High
648	Water/Steam Injection, Gas, Gas Turbine	028									55	95.0		
649	Water/Steam Injection, Distillate Oil, Gas Turbine	028									65	95.0		
699	Miscellaneous Integrated Controls	099	-	-	-	-	-	-	-	-	-	-	-	-
	CONTROL COMBINATIONS													
	NOx Controls:													
700	Low NOx Burners + Flue Gas Recirculation, Steel Furnace	NEW									55	80.0		
701	Low NOx Burner + Over Fire Air, Utility Boiler, Coal	NEW									30	70.0		
702	Low NOx Burner + Over Fire Air, Utility Boiler, Oil or Gas	NEW									40	60.0		
703	Low NOx Burners + Selective Catalytic Reduction, Annealing Furnace	NEW									70	95.0		
704	Low NOx Burners + Selective Non-Catalytic Reduction, Annealing Furnace	NEW									60	80.0		
705	Low NOx Burners + Over Fire Air + Selective Catalytic Reduction, Utility Boiler, Coal	NEW									80	95.0		
706	Water/Steam Injection + Selective Catalytic Reduction, Gas Turbine	NEW									60	95.0		
707	Air/Fuel Adjustment + Ignition Timing Retard, Rich Burn Gas	NEW									10	40.0		
708	Selective Non-Catalytic Reduction + Selective Catalytic Reduction, Utility Boiler, Gas/Oil	NEW									70	90.0		
709	Selective Non-Catalytic Reduction + Selective Catalytic Reduction, Utility Boiler, Coal	NEW									80	95.0		
	PM Controls:													
750	2 Gravity Collectors	NEW	10.0	> 99.0										

Appendix A: Control Technology Code Numbers and Normal Control Efficiency Range

CTC	CONTROL DEVICE/METHOD	OLD CEC	TOG Low	TOG High	ROG Low	ROG High	VOT Low	VOT High	POT Low	POT High	PIT Low	PIT High	GIT Low	GIT High
648	Water/Steam Injection, Gas, Gas Turbine	028												
649	Water/Steam Injection, Distillate Oil, Gas Turbine	028												
699	Miscellaneous Integrated Controls	099	-	-	-	-	-	-	-	-	-	-	-	-
	CONTROL COMBINATIONS													
	NOx Controls:													
700	Low NOx Burners + Flue Gas Recirculation, Steel Furnace	NEW												
701	Low NOx Burner + Over Fire Air, Utility Boiler, Coal	NEW												
702	Low NOx Burner + Over Fire Air, Utility Boiler, Oil or Gas	NEW												
703	Low NOx Burners + Selective Catalytic Reduction, Annealing Furnace	NEW												
704	Low NOx Burners + Selective Non-Catalytic Reduction, Annealing Furnace	NEW												
705	Low NOx Burners + Over Fire Air + Selective Catalytic Reduction, Utility Boiler, Coal	NEW												
706	Water/Steam Injection + Selective Catalytic Reduction, Gas Turbine	NEW												
707	Air/Fuel Adjustment + Ignition Timing Retard, Rich Burn Gas	NEW												
708	Selective Non-Catalytic Reduction + Selective Catalytic Reduction, Utility Boiler, Gas/Oil	NEW												
709	Selective Non-Catalytic Reduction + Selective Catalytic Reduction, Utility Boiler, Coal	NEW												
	PM Controls:													
750	2 Gravity Collectors	NEW												

Appendix A: Control Technology Code Numbers and Normal Control Efficiency Range

CTC	CONTROL DEVICE/METHOD	OLD CEC	PM Low		PM High	PM10 Low		PM10 High	PM2.5 Low		PM2.5 High	SOx Low	SOx High	NOx Low	NOx High	CO Low	CO High
751	Gravity Collector + Momentum Separator	NEW	30.0	>	99.0	10.0		30.0	5.0		10.0						
752	Gravity Collector + Centrifugal Collector	NEW	30.0	>	99.0	10.0		30.0	5.0		10.0						
753	Gravity Collector + Single Cyclone (Conventional)	NEW	70.0		99.0	30.0		90.0	0.0		40.0						
754	Gravity Collector + Single Cyclone (High Efficiency)	NEW	80.0		99.0	60.0		95.0	20.0		70.0						
755	Gravity Collector + Single Cyclone (High Throughput)	NEW	80.0		99.0	10.0		40.0	0.0		10.0						
756	Gravity Collector + Wet Scrubber (General)	NEW	55.0	>	99.9	55.0	>	99.9	25.0		97.0						
757	Gravity Collector + Tray-Type Scrubber	NEW	55.0		99.9	55.0		99.9	25.0		97.0						
758	Gravity Collector + Spray Chamber	NEW	70.0		99.9	70.0		99.9	25.0		97.0						
759	Gravity Collector + Mechanically-Aided Scrubber	NEW	70.0		99.9	70.0		99.9	25.0		97.0						
760	Gravity Collector + Packed-Bed Scrubber	NEW	85.0	>	99.9	85.0	>	99.9	25.0		97.0						
761	Gravity Collector + Venturi or Orifice Scrubber	NEW	90.0	>	99.9	90.0	>	99.9	25.0	>	99.0						
762	Gravity Collector + Condensation Scrubber	NEW	90.0	>	99.9	90.0	>	99.9	25.0	>	99.0						
763	Gravity Collector + Charged Scrubber	NEW	90.0	>	99.9	90.0	>	99.9	25.0	>	99.0						
764	Gravity Collector + Electrostatic Precipitator (Dry)	NEW	90.0	>	99.9	85.0		99.5	80.0	>	99.0						
765	Gravity Collector + Electrostatic Precipitator (Wet)	NEW	80.0	>	99.9	75.0		99.5	70.0	>	99.0						
766	Gravity Collector + Fabric Filter	NEW	90.0	>	99.9	85.0	>	99.9	80.0		99.9						
767	Gravity Collector + Gravel Bed Filter	NEW	90.0	>	99.5	85.0		99.0	80.0		99.0						
768	2 Momentum Separators	NEW	30.0	>	99.9	10.0		30.0	5.0		10.0						

Appendix A: Control Technology Code Numbers and Normal Control Efficiency Range

			TOG		ROG		VOT		POT		PIT		GIT	
CTC	CONTROL DEVICE/METHOD	OLD CEC	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
751	Gravity Collector + Momentum Separator	NEW							10.0	30.0	10.0	30.0		
752	Gravity Collector + Centrifugal Collector	NEW							10.0	30.0	10.0	30.0		
753	Gravity Collector + Single Cyclone (Conventional)	NEW							30.0	90.0	30.0	90.0		
754	Gravity Collector + Single Cyclone (High Efficiency)	NEW							60.0	95.0	60.0	95.0		
755	Gravity Collector + Single Cyclone (High Throughput)	NEW							10.0	40.0	10.0	40.0		
756	Gravity Collector + Wet Scrubber (General)	NEW							55.0	> 99.9	55.0	> 99.9		
757	Gravity Collector + Tray-Type Scrubber	NEW							55.0	99.9	55.0	99.9		
758	Gravity Collector + Spray Chamber	NEW							70.0	99.9	70.0	99.9		
759	Gravity Collector + Mechanically-Aided Scrubber	NEW							70.0	99.9	70.0	99.9		
760	Gravity Collector + Packed-Bed Scrubber	NEW							85.0	> 99.9	85.0	> 99.9		
761	Gravity Collector + Venturi or Orifice Scrubber	NEW							90.0	> 99.9	90.0	> 99.9		
762	Gravity Collector + Condensation Scrubber	NEW							90.0	> 99.9	90.0	> 99.9		
763	Gravity Collector + Charged Scrubber	NEW							90.0	> 99.9	90.0	> 99.9		
764	Gravity Collector + Electrostatic Precipitator (Dry)	NEW							85.0	99.5	85.0	99.5		
765	Gravity Collector + Electrostatic Precipitator (Wet)	NEW	50.0	70.0	50.0	70.0	50.0	70.0	75.0	99.5	75.0	99.5		
766	Gravity Collector + Fabric Filter	NEW							85.0	> 99.9	85.0	> 99.9		
767	Gravity Collector + Gravel Bed Filter	NEW							85.0	99.0	85.0	99.0		
768	2 Momentum Separators	NEW							10.0	30.0	10.0	30.0		

Appendix A: Control Technology Code Numbers and Normal Control Efficiency Range

CTC	CONTROL DEVICE/METHOD	OLD CEC	PM Low	PM High	PM10 Low	PM10 High	PM2.5 Low	PM2.5 High	SOx Low	SOx High	NOx Low	NOx High	CO Low	CO High
769	Momentum Separator + Centrifugal Collector	NEW	30.0	> 99.9	10.0	30.0	5.0	10.0						
770	Momentum Separator + Single Cyclone (Conventional)	NEW	70.0	99.0	30.0	90.0	0.0	40.0						
771	Momentum Separator + Single Cyclone (High Efficiency)	NEW	80.0	99.0	60.0	95.0	20.0	70.0						
772	Momentum Separator + Single Cyclone (High Throughput)	NEW	80.0	99.0	10.0	40.0	0.0	10.0						
773	Momentum Separator + Wet Scrubber (General)	NEW	55.0	> 99.9	55.0	> 99.0	25.0	97.0						
774	Momentum Separator + Tray-Type Scrubber	NEW	55.0	99.9	55.0	99.9	25.0	97.0						
775	Momentum Separator + Spray Chamber	NEW	70.0	99.9	70.0	99.9	25.0	97.0						
776	Momentum Separator + Mechanically-Aided Scrubber	NEW	70.0	99.9	70.0	99.9	25.0	97.0						
777	Momentum Separator + Packed-Bed Scrubber	NEW	85.0	> 99.9	85.0	> 99.9	25.0	97.0						
778	Momentum Separator + Venturi or Orifice Scrubber	NEW	90.0	> 99.9	90.0	> 99.9	25.0	> 99.0						
779	Momentum Separator + Condensation Scrubber	NEW	90.0	> 99.9	90.0	> 99.9	25.0	> 99.0						
780	Momentum Separator + Charged Scrubber	NEW	90.0	> 99.9	90.0	> 99.9	25.0	> 99.0						
781	Momentum Separator + Electrostatic Precipitator (Dry)	NEW	90.0	> 99.9	85.0	99.5	80.0	> 99.0						
782	Momentum Separator + Electrostatic Precipitator (Wet)	NEW	80.0	> 99.9	75.0	99.5	70.0	> 99.0						
783	Momentum Separator + Fabric Filter	NEW	90.0	> 99.9	85.0	> 99.9	80.0	99.9						
784	Momentum Separator + Gravel Bed Filter	NEW	90.0	> 99.5	85.0	99.0	80.0	99.0						
785	2 Centrifugal Collectors	NEW	30.0	> 99.9	10.0	30.0	5.0	10.0						
786	Centrifugal Collector + Blade-Type Mist Eliminator	NEW	80.0	99.0	80.0	98.0	50.0	70.0						

Appendix A: Control Technology Code Numbers and Normal Control Efficiency Range

CTC	CONTROL DEVICE/METHOD	OLD CEC	TOG Low	TOG High	ROG Low	ROG High	VOT Low	VOT High	POT Low	POT High	PIT Low	PIT High	GIT Low	GIT High
769	Momentum Separator + Centrifugal Collector	NEW							10.0	30.0	10.0	30.0		
770	Momentum Separator + Single Cyclone (Conventional)	NEW							30.0	90.0	30.0	90.0		
771	Momentum Separator + Single Cyclone (High Efficiency)	NEW							60.0	95.0	60.0	95.0		
772	Momentum Separator + Single Cyclone (High Throughput)	NEW							10.0	40.0	10.0	40.0		
773	Momentum Separator + Wet Scrubber (General)	NEW							55.0	> 99.0	55.0	> 99.0		
774	Momentum Separator + Tray-Type Scrubber	NEW							55.0	99.9	55.0	99.9		
775	Momentum Separator + Spray Chamber	NEW							70.0	99.9	70.0	99.9		
776	Momentum Separator + Mechanically-Aided Scrubber	NEW							70.0	99.9	70.0	99.9		
777	Momentum Separator + Packed-Bed Scrubber	NEW							85.0	> 99.9	85.0	> 99.9		
778	Momentum Separator + Venturi or Orifice Scrubber	NEW							90.0	> 99.9	90.0	> 99.9		
779	Momentum Separator + Condensation Scrubber	NEW							90.0	> 99.9	90.0	> 99.9		
780	Momentum Separator + Charged Scrubber	NEW							90.0	> 99.9	90.0	> 99.9		
781	Momentum Separator + Electrostatic Precipitator (Dry)	NEW							85.0	99.5	85.0	99.5		
782	Momentum Separator + Electrostatic Precipitator (Wet)	NEW	50.0	70.0	50.0	70.0	50.0	70.0	75.0	99.5	75.0	99.5		
783	Momentum Separator + Fabric Filter	NEW							85.0	> 99.9	85.0	> 99.9		
784	Momentum Separator + Gravel Bed Filter	NEW							85.0	99.0	85.0	99.0		
785	2 Centrifugal Collectors	NEW							10.0	30.0	10.0	30.0		
786	Centrifugal Collector + Blade-Type Mist Eliminator	NEW							80.0	98.0	80.0	98.0		

Appendix A: Control Technology Code Numbers and Normal Control Efficiency Range

			PM			PM10			PM2.5			SOx			NOx			CO		
CTC	CONTROL DEVICE/METHOD	OLD CEC	Low		High	Low		High	Low		High	Low		High	Low		High	Low		High
787	Centrifugal Collector + Mesh-Type Mist Eliminator	NEW	95.0	>	99.5	95.0	>	99.5	90.0		99.0									
788	Centrifugal Collector + Single Cyclone (Conventional)	NEW	70.0		99.0	30.0		90.0	0.0		40.0									
789	Centrifugal Collector + Single Cyclone (High Efficiency)	NEW	80.0		99.0	60.0		95.0	20.0		70.0									
790	Centrifugal Collector + Single Cyclone (High Throughput)	NEW	80.0		99.0	10.0		40.0	0.0		10.0									
791	Centrifugal Collector + Wet Scrubber (General)	NEW	55.0	>	99.9	55.0	>	99.0	25.0		97.0									
792	Centrifugal Collector + Tray-Type Scrubber	NEW	55.0		99.9	55.0		99.9	25.0		97.0									
793	Centrifugal Collector + Spray Chamber	NEW	70.0		99.9	70.0		99.9	25.0		97.0									
794	Centrifugal Collector + Mechanically-Aided Scrubber	NEW	70.0		99.9	70.0		99.9	25.0		97.0									
795	Centrifugal Collector + Packed-Bed Scrubber	NEW	85.0	>	99.9	85.0	>	99.9	25.0		97.0									
796	Centrifugal Collector + Venturi or Orifice Scrubber	NEW	90.0	>	99.9	90.0	>	99.9	25.0	>	99.0									
797	Centrifugal Collector + Condensation Scrubber	NEW	90.0	>	99.9	90.0	>	99.9	25.0	>	99.0									
798	Centrifugal Collector + Charged Scrubber	NEW	90.0	>	99.9	90.0	>	99.9	25.0	>	99.0									
799	Centrifugal Collector + Electrostatic Precipitator (Dry)	NEW	90.0	>	99.9	85.0		99.5	80.0	>	99.0									
800	Centrifugal Collector + Electrostatic Precipitator (Wet)	NEW	80.0	>	99.9	75.0		99.5	70.0	>	99.0									
801	Centrifugal Collector + Fabric Filter	NEW	90.0	>	99.9	85.0	>	99.9	80.0		99.9									
802	Centrifugal Collector + Gravel Bed Filter	NEW	90.0	>	99.5	85.0		99.0	80.0		99.0									
803	2 Single Cyclones (Conventional)	NEW	70.0		99.0	30.0		90.0	0.0		40.0									
804	Single Cyclone (Conventional) + Single Cyclone (High Efficiency)	NEW	80.0		99.0	60.0		95.0	20.0		70.0									

Appendix A: Control Technology Code Numbers and Normal Control Efficiency Range

			TOG		ROG		VOT		POT		PIT		GIT	
CTC	CONTROL DEVICE/METHOD	OLD CEC	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
787	Centrifugal Collector + Mesh-Type Mist Eliminator	NEW							95.0	> 99.5	95.0	> 99.5		
788	Centrifugal Collector + Single Cyclone (Conventional)	NEW							30.0	90.0	30.0	90.0		
789	Centrifugal Collector + Single Cyclone (High Efficiency)	NEW							60.0	95.0	60.0	95.0		
790	Centrifugal Collector + Single Cyclone (High Throughput)	NEW							10.0	40.0	10.0	40.0		
791	Centrifugal Collector + Wet Scrubber (General)	NEW							55.0	> 99.0	55.0	> 99.0		
792	Centrifugal Collector + Tray-Type Scrubber	NEW							55.0	99.9	55.0	99.9		
793	Centrifugal Collector + Spray Chamber	NEW							70.0	99.9	70.0	99.9		
794	Centrifugal Collector + Mechanically-Aided Scrubber	NEW							70.0	99.9	70.0	99.9		
795	Centrifugal Collector + Packed-Bed Scrubber	NEW							85.0	> 99.9	85.0	> 99.9		
796	Centrifugal Collector + Venturi or Orifice Scrubber	NEW							90.0	> 99.9	90.0	> 99.9		
797	Centrifugal Collector + Condensation Scrubber	NEW							90.0	> 99.9	90.0	> 99.9		
798	Centrifugal Collector + Charged Scrubber	NEW							90.0	> 99.9	90.0	> 99.9		
799	Centrifugal Collector + Electrostatic Precipitator (Dry)	NEW							85.0	99.5	85.0	99.5		
800	Centrifugal Collector + Electrostatic Precipitator (Wet)	NEW	50.0	70.0	50.0	70.0	50.0	70.0	75.0	99.5	75.0	99.5		
801	Centrifugal Collector + Fabric Filter	NEW							85.0	> 99.9	85.0	> 99.9		
802	Centrifugal Collector + Gravel Bed Filter	NEW							85.0	99.0	85.0	99.0		
803	2 Single Cyclones (Conventional)	NEW							30.0	90.0	30.0	90.0		
804	Single Cyclone (Conventional) + Single Cyclone (High Efficiency)	NEW							60.0	95.0	60.0	95.0		

Appendix A: Control Technology Code Numbers and Normal Control Efficiency Range

CTC	CONTROL DEVICE/METHOD	OLD CEC	PM Low	PM High	PM10 Low	PM10 High	PM2.5 Low	PM2.5 High	SOx Low	SOx High	NOx Low	NOx High	CO Low	CO High
805	Single Cyclone (Conventional) + Single Cyclone (High Throughput)	NEW	80.0	99.0	30.0	90.0	0.0	40.0						
806	Single Cyclone (Conventional) + Wet Scrubber (General)	NEW	70.0	> 99.9	55.0	> 99.0	25.0	97.0						
807	Single Cyclone (Conventional) + Tray-Type Scrubber	NEW	70.0	99.9	55.0	99.9	25.0	97.0						
808	Single Cyclone (Conventional) + Spray Chamber	NEW	70.0	99.9	70.0	99.9	25.0	97.0						
809	Single Cyclone (Conventional) + Mechanically-Aided Scrubber	NEW	70.0	99.9	70.0	99.9	25.0	97.0						
810	Single Cyclone (Conventional) + Packed-Bed Scrubber	NEW	85.0	> 99.9	85.0	> 99.9	25.0	97.0						
811	Single Cyclone (Conventional) + Venturi or Orifice Scrubber	NEW	90.0	> 99.9	90.0	> 99.9	25.0	> 99.0						
812	Single Cyclone (Conventional) + Condensation Scrubber	NEW	90.0	> 99.9	90.0	> 99.9	25.0	> 99.0						
813	Single Cyclone (Conventional) + Charged Scrubber	NEW	90.0	> 99.9	90.0	> 99.9	25.0	> 99.0						
814	Single Cyclone (Conventional) + Electrostatic Precipitator (Dry)	NEW	90.0	> 99.9	85.0	99.5	80.0	> 99.0						
815	Single Cyclone (Conventional) + Electrostatic Precipitator (Wet)	NEW	80.0	> 99.9	75.0	99.5	70.0	> 99.0						
816	Single Cyclone (Conventional) + Fabric Filter	NEW	90.0	> 99.9	85.0	> 99.9	80.0	99.9						
817	Single Cyclone (Conventional) + Gravel Bed Filter	NEW	90.0	> 99.5	85.0	99.0	80.0	99.0						
818	2 Single Cyclones (High Efficiency)	NEW	80.0	99.0	60.0	95.0	20.0	70.0						
819	Single Cyclone (High Efficiency) + Wet Scrubber (General)	NEW	80.0	> 99.9	60.0	> 99.0	25.0	97.0						
820	Single Cyclone (High Efficiency) + Tray-Type Scrubber	NEW	80.0	99.9	60.0	99.9	25.0	97.0						
821	Single Cyclone (High Efficiency) + Spray Chamber	NEW	80.0	99.9	70.0	99.9	25.0	97.0						
822	Single Cyclone (High Efficiency) + Mechanically-Aided Scrubber	NEW	80.0	99.9	70.0	99.9	25.0	97.0						

Appendix A: Control Technology Code Numbers and Normal Control Efficiency Range

CTC	CONTROL DEVICE/METHOD	OLD CEC	TOG Low	TOG High	ROG Low	ROG High	VOT Low	VOT High	POT Low	POT High	PIT Low	PIT High	GIT Low	GIT High
805	Single Cyclone (Conventional) + Single Cyclone (High Throughput)	NEW							30.0	90.0	30.0	90.0		
806	Single Cyclone (Conventional) + Wet Scrubber (General)	NEW							55.0	> 99.0	55.0	> 99.0		
807	Single Cyclone (Conventional) + Tray-Type Scrubber	NEW							55.0	99.9	55.0	99.9		
808	Single Cyclone (Conventional) + Spray Chamber	NEW							70.0	99.9	70.0	99.9		
809	Single Cyclone (Conventional) + Mechanically-Aided Scrubber	NEW							70.0	99.9	70.0	99.9		
810	Single Cyclone (Conventional) + Packed-Bed Scrubber	NEW							85.0	> 99.9	85.0	> 99.9		
811	Single Cyclone (Conventional) + Venturi or Orifice Scrubber	NEW							90.0	> 99.9	90.0	> 99.9		
812	Single Cyclone (Conventional) + Condensation Scrubber	NEW							90.0	> 99.9	90.0	> 99.9		
813	Single Cyclone (Conventional) + Charged Scrubber	NEW							90.0	> 99.9	90.0	> 99.9		
814	Single Cyclone (Conventional) + Electrostatic Precipitator (Dry)	NEW							85.0	99.5	85.0	99.5		
815	Single Cyclone (Conventional) + Electrostatic Precipitator (Wet)	NEW	50.0	70.0	50.0	70.0	50.0	70.0	75.0	99.5	75.0	99.5		
816	Single Cyclone (Conventional) + Fabric Filter	NEW							85.0	> 99.9	85.0	> 99.9		
817	Single Cyclone (Conventional) + Gravel Bed Filter	NEW							85.0	99.0	85.0	99.0		
818	2 Single Cyclones (High Efficiency)	NEW							60.0	95.0	60.0	95.0		
819	Single Cyclone (High Efficiency) + Wet Scrubber (General)	NEW							60.0	> 99.0	60.0	> 99.0		
820	Single Cyclone (High Efficiency) + Tray-Type Scrubber	NEW							60.0	99.9	60.0	99.9		
821	Single Cyclone (High Efficiency) + Spray Chamber	NEW							70.0	99.9	70.0	99.9		
822	Single Cyclone (High Efficiency) + Mechanically-Aided Scrubber	NEW							70.0	99.9	70.0	99.9		

Appendix A: Control Technology Code Numbers and Normal Control Efficiency Range

CTC	CONTROL DEVICE/METHOD	OLD CEC	PM Low	PM High	PM10 Low	PM10 High	PM2.5 Low	PM2.5 High	SOx Low	SOx High	NOx Low	NOx High	CO Low	CO High
823	Single Cyclone (High Efficiency) + Packed-Bed Scrubber	NEW	85.0	> 99.9	85.0	> 99.9	25.0	97.0						
824	Single Cyclone (High Efficiency) + Venturi or Orifice Scrubber	NEW	90.0	> 99.9	90.0	> 99.9	25.0	> 99.0						
825	Single Cyclone (High Efficiency) + Condensation Scrubber	NEW	90.0	> 99.9	90.0	> 99.9	25.0	> 99.0						
826	Single Cyclone (High Efficiency) + Charged Scrubber	NEW	90.0	> 99.9	90.0	> 99.9	25.0	> 99.0						
827	Single Cyclone (High Efficiency) + Electrostatic Precipitator (Dry)	NEW	90.0	> 99.9	85.0	99.5	80.0	> 99.0						
828	Single Cyclone (High Efficiency) + Electrostatic Precipitator (Wet)	NEW	80.0	> 99.9	75.0	99.5	70.0	> 99.0						
829	Single Cyclone (High Efficiency) + Fabric Filter	NEW	90.0	> 99.9	85.0	> 99.9	80.0	99.9						
830	Single Cyclone (High Efficiency) + Gravel Bed Filter	NEW	90.0	99.9	85.0	99.0	80.0	99.0						
831	2 Single Cyclones (High Throughput)	NEW	80.0	99.0	10.0	40.0	0.0	10.0						
832	Single Cyclone (High Throughput) + Single Cyclone (High Efficiency)	NEW	80.0	99.0	60.0	95.0	20.0	70.0						
833	Single Cyclone (High Throughput) + Wet Scrubber (General)	NEW	80.0	> 99.9	55.0	> 99.0	25.0	97.0						
834	Single Cyclone (High Throughput) + Tray-Type Scrubber	NEW	80.0	99.9	55.0	99.9	25.0	97.0						
835	Single Cyclone (High Throughput) + Spray Chamber	NEW	80.0	99.9	70.0	99.9	25.0	97.0						
836	Single Cyclone (High Throughput) + Mechanically-Aided Scrubber	NEW	80.0	99.9	70.0	99.9	25.0	97.0						
837	Single Cyclone (High Throughput) + Packed-Bed Scrubber	NEW	85.0	> 99.9	85.0	> 99.9	25.0	97.0						
838	Single Cyclone (High Throughput) + Venturi or Orifice Scrubber	NEW	90.0	> 99.9	90.0	> 99.9	25.0	> 99.0						
839	Single Cyclone (High Throughput) + Condensation Scrubber	NEW	90.0	> 99.9	90.0	> 99.9	25.0	> 99.0						
840	Single Cyclone (High Throughput) + Charged Scrubber	NEW	90.0	> 99.9	90.0	> 99.9	25.0	> 99.0						

Appendix A: Control Technology Code Numbers and Normal Control Efficiency Range

CTC	CONTROL DEVICE/METHOD	OLD CEC	TOG Low	TOG High	ROG Low	ROG High	VOT Low	VOT High	POT Low	POT High	PIT Low	PIT High	GIT Low	GIT High
823	Single Cyclone (High Efficiency) + Packed-Bed Scrubber	NEW							85.0	> 99.9	85.0	> 99.9		
824	Single Cyclone (High Efficiency) + Venturi or Orifice Scrubber	NEW							90.0	> 99.9	90.0	> 99.9		
825	Single Cyclone (High Efficiency) + Condensation Scrubber	NEW							90.0	> 99.9	90.0	> 99.9		
826	Single Cyclone (High Efficiency) + Charged Scrubber	NEW							90.0	> 99.9	90.0	> 99.9		
827	Single Cyclone (High Efficiency) + Electrostatic Precipitator (Dry)	NEW							85.0	99.5	85.0	99.5		
828	Single Cyclone (High Efficiency) + Electrostatic Precipitator (Wet)	NEW	50.0	70.0	50.0	70.0	50.0	70.0	75.0	99.5	75.0	99.5		
829	Single Cyclone (High Efficiency) + Fabric Filter	NEW							85.0	> 99.9	85.0	> 99.9		
830	Single Cyclone (High Efficiency) + Gravel Bed Filter	NEW							85.0	99.0	85.0	99.0		
831	2 Single Cyclones (High Throughput)	NEW							10.0	40.0	10.0	40.0		
832	Single Cyclone (High Throughput) + Single Cyclone (High Efficiency)	NEW							60.0	95.0	60.0	95.0		
833	Single Cyclone (High Throughput) + Wet Scrubber (General)	NEW							55.0	> 99.0	55.0	> 99.0		
834	Single Cyclone (High Throughput) + Tray-Type Scrubber	NEW							55.0	99.9	55.0	99.9		
835	Single Cyclone (High Throughput) + Spray Chamber	NEW							70.0	99.9	70.0	99.9		
836	Single Cyclone (High Throughput) + Mechanically-Aided Scrubber	NEW							70.0	99.9	70.0	99.9		
837	Single Cyclone (High Throughput) + Packed-Bed Scrubber	NEW							85.0	> 99.9	85.0	> 99.9		
838	Single Cyclone (High Throughput) + Venturi or Orifice Scrubber	NEW							90.0	> 99.9	90.0	> 99.9		
839	Single Cyclone (High Throughput) + Condensation Scrubber	NEW							90.0	> 99.9	90.0	> 99.9		
840	Single Cyclone (High Throughput) + Charged Scrubber	NEW							90.0	> 99.9	90.0	> 99.9		

Appendix A: Control Technology Code Numbers and Normal Control Efficiency Range

CTC	CONTROL DEVICE/METHOD	OLD CEC	PM Low		PM High	PM10 Low		PM10 High	PM2.5 Low		PM2.5 High	SOx Low	SOx High	NOx Low	NOx High	CO Low	CO High
841	Single Cyclone (High Throughput) + Electrostatic Precipitator (Dry)	NEW	90.0	>	99.9	85.0		99.5	80.0	>	99.0						
842	Single Cyclone (High Throughput) + Electrostatic Precipitator (Wet)	NEW	80.0	>	99.9	75.0		99.5	70.0	>	99.0						
843	Single Cyclone (High Throughput) + Fabric Filter	NEW	90.0	>	99.9	85.0	>	99.9	80.0		99.9						
844	Single Cyclone (High Throughput) + Gravel Bed Filter	NEW	90.0		99.9	85.0		99.0	80.0		99.0						
845	2 Multiple Cyclones with Fly Ash Reinjection	NEW	70.0		99.0	35.0		85.0	20.0		60.0						
846	Multiple Cyclone with Fly Ash Reinjection + Wet Scrubber (General)	NEW	70.0	>	99.9	55.0	>	99.0	25.0		97.0						
847	Multiple Cyclone with Fly Ash Reinjection + Tray-Type Scrubber	NEW	70.0		99.9	55.0		99.9	25.0		97.0						
848	Multiple Cyclone with Fly Ash Reinjection + Spray Chamber	NEW	70.0		99.9	70.0		99.9	25.0		97.0						
849	Multiple Cyclone with Fly Ash Reinjection + Mechanically-Aided Scrubber	NEW	70.0		99.9	70.0		99.9	25.0		97.0						
850	Multiple Cyclone with Fly Ash Reinjection + Packed-Bed Scrubber	NEW	85.0	>	99.9	85.0	>	99.9	25.0		97.0						
851	Multiple Cyclone with Fly Ash Reinjection + Venturi or Orifice	NEW	90.0	>	99.9	90.0	>	99.9	25.0	>	99.0						
852	Multiple Cyclone with Fly Ash Reinjection + Condensation Scrubber	NEW	90.0	>	99.9	90.0	>	99.9	25.0	>	99.0						
853	Multiple Cyclone with Fly Ash Reinjection + Charged Scrubber	NEW	90.0	>	99.9	90.0	>	99.9	25.0	>	99.0						
854	Multiple Cyclone with Fly Ash Reinjection + Electrostatic Precipitator (Dry)	NEW	90.0	>	99.9	85.0		99.5	80.0		99.3						
855	Multiple Cyclone with Fly Ash Reinjection + Electrostatic Precipitator	NEW	80.0	>	99.9	75.0		99.5	70.0		99.3						
856	Multiple Cyclone with Fly Ash Reinjection + Fabric Filter	NEW	90.0	>	99.9	85.0	>	99.9	80.0		99.9						
857	Multiple Cyclone with Fly Ash Reinjection + Gravel Bed Filter	NEW	90.0		99.9	85.0		99.0	80.0		99.0						

Appendix A: Control Technology Code Numbers and Normal Control Efficiency Range

CTC	CONTROL DEVICE/METHOD	OLD CEC	TOG Low	TOG High	ROG Low	ROG High	VOT Low	VOT High	POT Low	POT High	PIT Low	PIT High	GIT Low	GIT High
841	Single Cyclone (High Throughput) + Electrostatic Precipitator (Dry)	NEW							85.0	99.5	85.0	99.5		
842	Single Cyclone (High Throughput) + Electrostatic Precipitator (Wet)	NEW	50.0	70.0	50.0	70.0	50.0	70.0	75.0	99.5	75.0	99.5		
843	Single Cyclone (High Throughput) + Fabric Filter	NEW							85.0	> 99.9	85.0	> 99.9		
844	Single Cyclone (High Throughput) + Gravel Bed Filter	NEW							85.0	99.0	85.0	99.0		
845	2 Multiple Cyclones with Fly Ash Reinjection	NEW							35.0	85.0	35.0	85.0		
846	Multiple Cyclone with Fly Ash Reinjection + Wet Scrubber (General)	NEW							55.0	> 99.0	55.0	> 99.0		
847	Multiple Cyclone with Fly Ash Reinjection + Tray-Type Scrubber	NEW							55.0	99.9	55.0	99.9		
848	Multiple Cyclone with Fly Ash Reinjection + Spray Chamber	NEW							70.0	99.9	70.0	99.9		
849	Multiple Cyclone with Fly Ash Reinjection + Mechanically-Aided Scrubber	NEW							70.0	99.9	70.0	99.9		
850	Multiple Cyclone with Fly Ash Reinjection + Packed-Bed Scrubber	NEW							85.0	> 99.9	85.0	> 99.9		
851	Multiple Cyclone with Fly Ash Reinjection + Venturi or Orifice	NEW							90.0	> 99.9	90.0	> 99.9		
852	Multiple Cyclone with Fly Ash Reinjection + Condensation Scrubber	NEW							90.0	> 99.9	90.0	> 99.9		
853	Multiple Cyclone with Fly Ash Reinjection + Charged Scrubber	NEW							90.0	> 99.9	90.0	> 99.9		
854	Multiple Cyclone with Fly Ash Reinjection + Electrostatic Precipitator (Dry)	NEW							85.0	99.5	85.0	99.5		
855	Multiple Cyclone with Fly Ash Reinjection + Electrostatic Precipitator	NEW	50.0	70.0	50.0	70.0	50.0	70.0	75.0	99.5	75.0	99.5		
856	Multiple Cyclone with Fly Ash Reinjection + Fabric Filter	NEW							85.0	> 99.9	85.0	> 99.9		
857	Multiple Cyclone with Fly Ash Reinjection + Gravel Bed Filter	NEW							85.0	99.0	85.0	99.0		

Appendix A: Control Technology Code Numbers and Normal Control Efficiency Range

CTC	CONTROL DEVICE/METHOD	OLD CEC	PM Low	PM High	PM10 Low	PM10 High	PM2.5 Low	PM2.5 High	SOx Low	SOx High	NOx Low	NOx High	CO Low	CO High
858	2 Multiple Cyclones without Fly Ash Reinjection	NEW	80.0	99.0	50.0	95.0	20.0	70.0						
859	Multiple Cyclone without Fly Ash Reinjection + Wet Scrubber (General)	NEW	80.0	> 99.9	55.0	> 99.0	25.0	97.0						
860	Multiple Cyclone without Fly Ash Reinjection + Tray-Type Scrubber	NEW	80.0	99.9	55.0	99.9	25.0	97.0						
861	Multiple Cyclone without Fly Ash Reinjection + Spray Chamber	NEW	80.0	99.9	70.0	99.9	25.0	97.0						
862	Multiple Cyclone without Fly Ash Reinjection + Mechanically-Aided Scrubber	NEW	80.0	99.9	70.0	99.9	25.0	97.0						
863	Multiple Cyclone without Fly Ash Reinjection + Packed-Bed Scrubber	NEW	85.0	> 99.9	85.0	> 99.9	25.0	97.0						
864	Multiple Cyclone without Fly Ash Reinjection + Venturi or Orifice	NEW	90.0	> 99.9	90.0	> 99.9	25.0	> 99.0						
865	Multiple Cyclone without Fly Ash Reinjection + Condensation Scrubber	NEW	90.0	> 99.9	90.0	> 99.9	25.0	> 99.0						
866	Multiple Cyclone without Fly Ash Reinjection + Charged Scrubber	NEW	90.0	> 99.9	90.0	> 99.9	25.0	> 99.0						
867	Multiple Cyclone without Fly Ash Reinjection + Electrostatic Precipitator (Dry)	NEW	90.0	> 99.9	85.0	99.5	80.0	> 99.0						
868	Multiple Cyclone without Fly Ash Reinjection + Electrostatic Precipitator (Wet)	NEW	80.0	> 99.9	75.0	99.5	70.0	> 99.0						
869	Multiple Cyclone without Fly Ash Reinjection + Fabric Filter	NEW	90.0	> 99.9	85.0	> 99.9	80.0	99.9						
870	Multiple Cyclone without Fly Ash Reinjection + Gravel Bed Filter	NEW	90.0	99.9	85.0	99.0	80.0	99.0						
871	2 Electrostatic Precipitators (Dry)	NEW	95.0	> 99.9	95.0	> 99.9	90.0	> 99.9						
872	Electrostatic Precipitator (Dry) + Fabric Filter	NEW	95.0	> 99.9	95.0	> 99.9	90.0	> 99.9						
873	Electrostatic Precipitator (Dry) + Wet Scrubber (General)	NEW	90.0	> 99.9	90.0	> 99.9	80.0	> 99.9						
874	Electrostatic Precipitator (Dry) + Tray-Type Scrubber	NEW	90.0	> 99.9	90.0	> 99.9	80.0	> 99.0						

Appendix A: Control Technology Code Numbers and Normal Control Efficiency Range

CTC	CONTROL DEVICE/METHOD	OLD CEC	TOG Low	TOG High	ROG Low	ROG High	VOT Low	VOT High	POT Low	POT High	PIT Low	PIT High	GIT Low	GIT High
858	2 Multiple Cyclones without Fly Ash Reinjection	NEW							50.0	95.0	50.0	95.0		
859	Multiple Cyclone without Fly Ash Reinjection + Wet Scrubber (General)	NEW							55.0	> 99.0	55.0	> 99.0		
860	Multiple Cyclone without Fly Ash Reinjection + Tray-Type Scrubber	NEW							55.0	99.9	55.0	99.9		
861	Multiple Cyclone without Fly Ash Reinjection + Spray Chamber	NEW							70.0	99.9	70.0	99.9		
862	Multiple Cyclone without Fly Ash Reinjection + Mechanically-Aided Scrubber	NEW							70.0	99.9	70.0	99.9		
863	Multiple Cyclone without Fly Ash Reinjection + Packed-Bed Scrubber	NEW							85.0	> 99.9	85.0	> 99.9		
864	Multiple Cyclone without Fly Ash Reinjection + Venturi or Orifice	NEW							90.0	> 99.9	90.0	> 99.9		
865	Multiple Cyclone without Fly Ash Reinjection + Condensation Scrubber	NEW							90.0	> 99.9	90.0	> 99.9		
866	Multiple Cyclone without Fly Ash Reinjection + Charged Scrubber	NEW							90.0	> 99.9	90.0	> 99.9		
867	Multiple Cyclone without Fly Ash Reinjection + Electrostatic Precipitator (Dry)	NEW							85.0	99.5	85.0	99.5		
868	Multiple Cyclone without Fly Ash Reinjection + Electrostatic Precipitator (Wet)	NEW	50.0	70.0	50.0	70.0	50.0	70.0	75.0	99.5	75.0	99.5		
869	Multiple Cyclone without Fly Ash Reinjection + Fabric Filter	NEW							85.0	> 99.9	85.0	> 99.9		
870	Multiple Cyclone without Fly Ash Reinjection + Gravel Bed Filter	NEW							85.0	99.0	85.0	99.0		
871	2 Electrostatic Precipitators (Dry)	NEW							95.0	> 99.9	95.0	> 99.9		
872	Electrostatic Precipitator (Dry) + Fabric Filter	NEW							95.0	> 99.9	95.0	> 99.9		
873	Electrostatic Precipitator (Dry) + Wet Scrubber (General)	NEW							90.0	> 99.9	90.0	> 99.9		
874	Electrostatic Precipitator (Dry) + Tray-Type Scrubber	NEW							90.0	> 99.9	90.0	> 99.9		

Appendix A: Control Technology Code Numbers and Normal Control Efficiency Range

CTC	CONTROL DEVICE/METHOD	OLD CEC	PM Low		PM High	PM10 Low		PM10 High	PM2.5 Low		PM2.5 High	SOx Low	SOx High	NOx Low	NOx High	CO Low	CO High
875	Electrostatic Precipitator (Dry) + Spray Chamber	NEW	90.0	>	99.9	90.0	>	99.9	80.0	>	99.0						
876	Electrostatic Precipitator (Dry) + Mechanically Aided Scrubber	NEW	90.0	>	99.9	90.0	>	99.9	80.0	>	99.0						
877	Electrostatic Precipitator (Dry) + Packed Bed Scrubber	NEW	90.0	>	99.9	90.0	>	99.9	80.0	>	99.0						
878	Electrostatic Precipitator (Dry) + Venturi or Orifice Scrubber	NEW	95.0	>	99.9	95.0	>	99.9	90.0	>	99.9						
879	Electrostatic Precipitator (Dry) + Condensation Scrubber	NEW	95.0	>	99.9	95.0	>	99.9	90.0	>	99.9						
880	Electrostatic Precipitator (Dry) + Charged Scrubber	NEW	95.0	>	99.9	95.0	>	99.9	90.0	>	99.9						
881	2 Fabric Filters	NEW	95.0	>	99.9	95.0	>	99.9	90.0	>	99.9						
882	Fabric Filter + Wet Scrubber (General)	NEW	90.0	>	99.9	90.0	>	99.9	80.0	>	99.9						
883	Fabric Filter + Tray-Type Scrubber	NEW	90.0	>	99.9	90.0	>	99.9	80.0		99.9						
884	Fabric Filter + Spray Chamber	NEW	90.0	>	99.9	90.0	>	99.9	80.0		99.9						
885	Fabric Filter + Mechanically Aided Scrubber	NEW	90.0	>	99.9	90.0	>	99.9	80.0		99.9						
886	Fabric Filter + Packed Bed Scrubber	NEW	90.0	>	99.9	90.0	>	99.9	80.0		99.9						
887	Fabric Filter + Venturi or Orifice Scrubber	NEW	95.0	>	99.9	95.0	>	99.9	90.0	>	99.9						
888	Fabric Filter + Condensation Scrubber	NEW	95.0	>	99.9	95.0	>	99.9	90.0	>	99.9						
889	Fabric Filter + Charged Scrubber	NEW	95.0	>	99.9	95.0	>	99.9	90.0	>	99.9						
890	Fabric Filter + Electrostatic Precipitator (Wet)	NEW	95.0	>	99.9	95.0	>	99.9	90.0	>	99.9						
891	Gravel Bed Filter + Fabric Filter	NEW	90.0	>	99.9	90.0	>	99.9	80.0		99.9						
892	2 Wet Scrubbers (General, Not Classified)	NEW	70.0	>	99.9	70.0	>	99.9	25.0	>	99.0						

Appendix A: Control Technology Code Numbers and Normal Control Efficiency Range

			TOG		ROG		VOT		POT		PIT		GIT	
CTC	CONTROL DEVICE/METHOD	OLD CEC	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
875	Electrostatic Precipitator (Dry) + Spray Chamber	NEW							90.0	> 99.9	90.0	> 99.9		
876	Electrostatic Precipitator (Dry) + Mechanically Aided Scrubber	NEW							90.0	> 99.9	90.0	> 99.9		
877	Electrostatic Precipitator (Dry) + Packed Bed Scrubber	NEW							90.0	> 99.9	90.0	> 99.9		
878	Electrostatic Precipitator (Dry) + Venturi or Orifice Scrubber	NEW							95.0	> 99.9	95.0	> 99.9		
879	Electrostatic Precipitator (Dry) + Condensation Scrubber	NEW							95.0	> 99.9	95.0	> 99.9		
880	Electrostatic Precipitator (Dry) + Charged Scrubber	NEW							95.0	> 99.9	95.0	> 99.9		
881	2 Fabric Filters	NEW							95.0	> 99.9	95.0	> 99.9		
882	Fabric Filter + Wet Scrubber (General)	NEW							90.0	> 99.9	90.0	> 99.9		
883	Fabric Filter + Tray-Type Scrubber	NEW							90.0	> 99.9	90.0	> 99.9		
884	Fabric Filter + Spray Chamber	NEW							90.0	> 99.9	90.0	> 99.9		
885	Fabric Filter + Mechanically Aided Scrubber	NEW							90.0	> 99.9	90.0	> 99.9		
886	Fabric Filter + Packed Bed Scrubber	NEW							90.0	> 99.9	90.0	> 99.9		
887	Fabric Filter + Venturi or Orifice Scrubber	NEW							95.0	> 99.9	95.0	> 99.9		
888	Fabric Filter + Condensation Scrubber	NEW							95.0	> 99.9	95.0	> 99.9		
889	Fabric Filter + Charged Scrubber	NEW							95.0	> 99.9	95.0	> 99.9		
890	Fabric Filter + Electrostatic Precipitator (Wet)	NEW	50.0	70.0	50.0	70.0	50.0	70.0	95.0	> 99.9	95.0	> 99.9		
891	Gravel Bed Filter + Fabric Filter	NEW							90.0	> 99.9	90.0	> 99.9		
892	2 Wet Scrubbers (General, Not Classified)	NEW							70.0	> 99.9	70.0	> 99.9		

Appendix A: Control Technology Code Numbers and Normal Control Efficiency Range

CTC	CONTROL DEVICE/METHOD	OLD CEC	PM Low		PM High	PM10 Low		PM10 High	PM2.5 Low		PM2.5 High	SOx Low	SOx High	NOx Low	NOx High	CO Low	CO High
893	2 Venturi or Orifice Scrubbers	NEW	90.0	>	99.9	90.0	>	99.9	70.0	>	99.9						
894	2 Tray-Type Scrubbers (Impingement Plate, Perforated Plate, Horizontal Impingement-Plate (Baffle))	NEW	70.0	>	99.0	70.0	>	99.0	25.0		99.0						
895	Tray-Type Scrubber + Spray Chamber	NEW	70.0	>	99.9	70.0	>	99.0	25.0		99.0						
896	Tray-Type Scrubber + Mechanically Aided Scrubber	NEW	70.0	>	99.9	70.0	>	99.0	25.0		99.0						
897	Tray-Type Scrubber + Packed Bed Scrubber	NEW	85.0	>	99.0	85.0	>	99.0	25.0		99.0						
898	Tray-Type Scrubber + Venturi or Orifice Scrubber	NEW	90.0	>	99.9	90.0	>	99.9	25.0	>	99.0						
899	Tray-Type Scrubber + Condensation Scrubber	NEW	90.0	>	99.9	90.0	>	99.9	25.0	>	99.0						
900	Tray-Type Scrubber + Charged Scrubber	NEW	90.0	>	99.9	90.0	>	99.9	25.0	>	99.0						
901	2 Spray Chambers (Spray Tower, Cyclonic Spray Tower, Vane-Type	NEW	80.0	>	99.9	80.0	>	99.9	25.0	>	99.0						
902	Spray Chamber + Mechanically Aided Scrubber	NEW	80.0	>	99.9	80.0	>	99.0	25.0		99.0						
903	Spray Chamber + Packed Bed Scrubber	NEW	85.0	>	99.9	85.0	>	99.0	25.0		99.0						
904	Spray Chamber + Venturi or Orifice Scrubber	NEW	90.0	>	99.9	90.0	>	99.9	25.0	>	99.0						
905	Spray Chamber + Condensation Scrubber	NEW	90.0	>	99.9	90.0	>	99.9	25.0	>	99.0						
906	Spray Chamber + Charged Scrubber	NEW	90.0	>	99.9	90.0	>	99.9	25.0	>	99.0						
907	2 Mechanically-Aided Scrubbers	NEW	80.0	>	99.9	80.0	>	99.9	70.0	>	99.0						
908	Mechanically Aided Scrubber + Packed Bed Scrubber	NEW	85.0	>	99.0	85.0	>	99.0	25.0		99.0						
909	Mechanically Aided Scrubber + Venturi or Orifice Scrubber	NEW	90.0	>	99.9	90.0	>	99.9	25.0	>	99.0						
910	Mechanically Aided Scrubber + Condensation Scrubber	NEW	90.0	>	99.9	90.0	>	99.9	25.0	>	99.0						

Appendix A: Control Technology Code Numbers and Normal Control Efficiency Range

CTC	CONTROL DEVICE/METHOD	OLD CEC	TOG Low	TOG High	ROG Low	ROG High	VOT Low	VOT High	POT Low	POT High	PIT Low	PIT High	GIT Low	GIT High
893	2 Venturi or Orifice Scrubbers	NEW							90.0	> 99.9	90.0	> 99.9		
894	2 Tray-Type Scrubbers (Impingement Plate, Perforated Plate, Horizontal Impingement-Plate (Baffle))	NEW							70.0	> 99.0	70.0	> 99.0		
895	Tray-Type Scrubber + Spray Chamber	NEW							70.0	> 99.0	70.0	> 99.0		
896	Tray-Type Scrubber + Mechanically Aided Scrubber	NEW							70.0	> 99.0	70.0	> 99.0		
897	Tray-Type Scrubber + Packed Bed Scrubber	NEW							85.0	> 99.0	85.0	> 99.0		
898	Tray-Type Scrubber + Venturi or Orifice Scrubber	NEW							90.0	> 99.9	90.0	> 99.9		
899	Tray-Type Scrubber + Condensation Scrubber	NEW							90.0	> 99.9	90.0	> 99.9		
900	Tray-Type Scrubber + Charged Scrubber	NEW							90.0	> 99.9	90.0	> 99.9		
901	2 Spray Chambers (Spray Tower, Cyclonic Spray Tower, Vane-Type	NEW							80.0	> 99.9	80.0	> 99.9		
902	Spray Chamber + Mechanically Aided Scrubber	NEW							80.0	> 99.0	80.0	> 99.0		
903	Spray Chamber + Packed Bed Scrubber	NEW							85.0	> 99.0	85.0	> 99.0		
904	Spray Chamber + Venturi or Orifice Scrubber	NEW							90.0	> 99.9	90.0	> 99.9		
905	Spray Chamber + Condensation Scrubber	NEW							90.0	> 99.9	90.0	> 99.9		
906	Spray Chamber + Charged Scrubber	NEW							90.0	> 99.9	90.0	> 99.9		
907	2 Mechanically-Aided Scrubbers	NEW							80.0	> 99.9	80.0	> 99.9		
908	Mechanically Aided Scrubber + Packed Bed Scrubber	NEW							85.0	> 99.0	85.0	> 99.0		
909	Mechanically Aided Scrubber + Venturi or Orifice Scrubber	NEW							90.0	> 99.9	90.0	> 99.9		
910	Mechanically Aided Scrubber + Condensation Scrubber	NEW							90.0	> 99.9	90.0	> 99.9		

Appendix A: Control Technology Code Numbers and Normal Control Efficiency Range

			PM			PM10			PM2.5			SOx		NOx		CO	
CTC	CONTROL DEVICE/METHOD	OLD CEC	Low		High	Low		High	Low		High	Low	High	Low	High	Low	High
911	Mechanically Aided Scrubber + Charged Scrubber	NEW	90.0	>	99.9	90.0	>	99.9	25.0	>	99.0						
912	2 Packed-Bed Scrubbers (Fiber-Bed, Moving-Bed, Cross-Flow, Grid-Packed)	NEW	85.0	>	99.0	85.0	>	99.0	25.0		99.0						
913	Packed Bed Scrubber + Venturi or Orifice Scrubber	NEW	90.0	>	99.9	90.0	>	99.9	25.0	>	99.0						
914	Packed Bed Scrubber + Condensation Scrubber	NEW	90.0	>	99.9	90.0	>	99.9	25.0	>	99.0						
915	Packed Bed Scrubber + Charged Scrubber	NEW	90.0	>	99.9	90.0	>	99.9	25.0	>	99.0						
916	2 Blade-Type Mist Eliminators	NEW	90.0		99.9	90.0		99.9	60.0		70.0						
917	2 Mesh-Type Mist Eliminators	NEW	95.0	>	99.9	95.0	>	99.9	95.0		99.9						
918	Blade-Type Mist Eliminator + Mesh-Type Mist Eliminator	NEW	95.0	>	99.9	95.0	>	99.9	95.0		99.9						
919	Plastic Balls for Electroplating Tanks + Blade-Type Mist Eliminator	NEW	80.0		98.0	80.0		98.0	50.0		70.0						
920	Plastic Balls for Electroplating Tanks + Mesh-Type Mist Eliminator	NEW	95.0		99.9	95.0		99.9	95.0		99.9						

Appendix A: Control Technology Code Numbers and Normal Control Efficiency Range

CTC	CONTROL DEVICE/METHOD	OLD CEC	TOG Low	TOG High	ROG Low	ROG High	VOT Low	VOT High	POT Low	POT High	PIT Low	PIT High	GIT Low	GIT High
911	Mechanically Aided Scrubber + Charged Scrubber	NEW							90.0	> 99.9	90.0	> 99.9		
912	2 Packed-Bed Scrubbers (Fiber-Bed, Moving-Bed, Cross-Flow, Grid-Packed)	NEW							85.0	> 99.0	85.0	> 99.0		
913	Packed Bed Scrubber + Venturi or Orifice Scrubber	NEW							90.0	> 99.9	90.0	> 99.9		
914	Packed Bed Scrubber + Condensation Scrubber	NEW							90.0	> 99.9	90.0	> 99.9		
915	Packed Bed Scrubber + Charged Scrubber	NEW							90.0	> 99.9	90.0	> 99.9		
916	2 Blade-Type Mist Eliminators	NEW							90.0	99.9	90.0	99.9		
917	2 Mesh-Type Mist Eliminators	NEW							95.0	> 99.9	95.0	> 99.9		
918	Blade-Type Mist Eliminator + Mesh-Type Mist Eliminator	NEW							95.0	> 99.9	95.0	> 99.9		
919	Plastic Balls for Electroplating Tanks + Blade-Type Mist Eliminator	NEW									80.0	98.0		
920	Plastic Balls for Electroplating Tanks + Mesh-Type Mist Eliminator	NEW									95.0	99.9		

IDENTIFICATION OF POINT SOURCE EMISSION CONTROLS AND DETERMINATION OF THEIR EFFICIENCIES AND COSTS

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ABSTRACT

The California Air Resources Board (CARB) is responsible for compiling a statewide air pollutant emissions inventory and improving the inventory as necessary to meet its objectives and those of its emissions inventory clients (e.g., local air quality districts). As part of this process, CARB requires a comprehensive, up-to-date list of air pollution controls that are used for reducing emissions from point sources and the accompanying range of control efficiencies typically achieved for each pollutant. Among other uses, this information is used by CARB and local air district staff during the evaluation of permit applications and emission inventory reporting.

By 1997, the point source control listing that was in use by CARB and the districts had become out of date (e.g., newer controls were not represented, ranges of control efficiencies were overly broad). To update this listing, a comprehensive review of relevant air pollution data sources was conducted. Among these sources were:

- the United States Environmental Protection Agency's (EPA's) AP-42, Control Techniques Guidelines, Alternative Control Technique documents, and other reports on control equipment for criteria and hazardous air pollutants (HAPs, also referred to as air toxics);
- the State and Territorial Air Pollution Program Administrators/Association of Local Air Pollution Control Officials control technology reports;
- the California Air Pollution Control Officers' Association's Reasonably Available Control Technology/Best Available Control Technology clearinghouse;
- standard air pollution references (e.g., the *Air Pollution Engineering Manual*);
- in-house control technology assessments previously prepared by E.H. Pechan & Associates, Inc.; and
- recent technical literature including the Air and Waste Management Association technical papers, periodicals, the internet, and telephone contacts (EPA, trade organizations, and manufacturers).

The data gathered from these sources were used in developing descriptions of each control technology and establishing the expected control efficiency range achieved in actual practice. Where available, information on the costs of these controls, in terms of cost effectiveness (annualized cost per ton of pollutant reduced, in 1995 dollars), was incorporated into the control description. Information for most of the commonly used equipment were well documented and based on in-depth studies. Data for less-used and emerging technology equipment were often sparse and/or vague. In many of these cases, it was necessary to apply professional judgment in establishing efficiency ranges and costs.

An updated printout of CARB's database of point source air pollution controls is contained in this report as well as descriptions of the control technologies, ranges of typical operating control efficiencies, and available cost data. A limited effort was made to incorporate information on point source control of air toxics. This effort included the development of an appendix which lists all California air toxics and EPA HAPs and defines each as a volatile organic toxic, a particulate organic toxic, a particulate inorganic toxic, a gaseous inorganic toxic, or some combination of these categories. This toxics categorization scheme can then be used to assign approximate control ranges for many of the control technologies presented in this report.

During the study, researchers strived to provide estimates of reasonable upper and lower bounds on the control efficiencies. Whenever possible, these ranges were based on test data, however, in many cases, professional judgement was used to establish a reasonable range. Therefore, the user should be cautioned that, in any given situation, a control technology could achieve efficiencies outside of the estimated range. For assessments dealing with permit review, risk assessment, and other regulatory studies, testing of the source should be required.

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CONTENTS (Continued)

EXECUTIVE SUMMARY

The California Air Resources Board (CARB) is responsible for compiling a statewide air pollutant emissions inventory and improving the inventory as necessary to meet its objectives and those of its emissions inventory clients (e.g., local air quality districts). As part of this process, CARB requires a comprehensive, up-to-date list of air pollution controls that are used for reducing emissions from point sources and the accompanying range of control efficiencies typically achieved for each pollutant.

The current list of control technology codes used by CARB was developed by the United States Environmental Protection Agency (EPA) over 15 years ago for use in the National Emissions Data System and does not include cost data. Due to the age of this listing (hereafter referred to as the control technology database), a number of new technologies do not appear, or have to be considered as being a part of a much more broad category. In addition, the control efficiency data are outdated or the range is so broad that the information is of limited value. Finally, the existing control data only apply to criteria pollutants. CARB would also like to include information on control of air toxics (however, only a small portion of the resources allocated to this project were to be used in assessing control efficiencies for air toxics).

The contents of this report include: a printout of an update to the control technology database; a description of the control technologies covered; ranges of typical control efficiencies for each control technology; and available cost data range in terms of cost effectiveness (i.e., annualized costs per ton of pollutant reduced, in 1995 dollars).

To update the existing control technology database, a comprehensive review of relevant air pollution data sources was conducted. Among these sources were:

- the EPA's AP-42, Control Technique Guidelines, Alternative Control Technique documents, and other reports on control equipment for criteria and hazardous air pollutants (also referred to as air toxics);
- the State and Territorial Air Pollution Program Administrators/Association of Local Air Pollution Control Officials control technology reports;
- the California Air Pollution Control Officers' Association's Reasonably Available Control Technology/Best Available Control Technology clearinghouse;
- standard air pollution references (e.g., the *Air Pollution Engineering Manual*);
- in-house control technology assessments previously prepared by E.H. Pechan & Associates, Inc. (Pechan); and

- recent technical literature including the Air and Waste Management Association technical papers, periodicals, the internet, and telephone contacts (EPA, trade organizations, and manufacturers).

The data gathered from these sources were used in preparing descriptions of each control device, and establishing the expected control efficiency range and cost effectiveness (in 1995 dollars) achieved in practice. Information for most of the commonly-used control technologies were well documented and are based on in-depth studies. Data for less-used and emerging technologies were often sparse and/or vague. In many of these cases, it was necessary to apply professional judgment in establishing efficiency ranges and costs. In some cases, costs could not be determined.

The air pollutants addressed in this study include three groups of particulate matter. These are total suspended particulate, or TSP (referred to in this report as simply "particulate matter," or PM), particulate matter less than 10 microns in diameter, and particulate matter less than 2.5 microns. The other pollutants addressed are oxides of sulfur, oxides of nitrogen, carbon monoxide, total organic gases, reactive organic gases, and air toxics.

While CARB desired to include available information on the efficiencies of various technologies in controlling air toxics emissions, a limited effort was to be made in gathering this data. To assist a user in assessing air toxics control efficiencies, a categorization scheme was developed for toxics based on similar chemical and physical characteristics. This categorization scheme involved grouping each California- or EPA-listed toxic in one or more of the four following categories: volatile organic toxics; particulate organic toxics; particulate inorganic toxics; and gaseous inorganic toxics.

Control efficiencies are presented for the primary pollutant that the technology is designed to control. Some technologies may incidentally control other pollutants, and, where data are available, efficiency ranges are presented. In general, control efficiencies are expressed in whole numbers. Where sufficient documentation exists, control efficiencies greater than 99 percent are expressed in tenths of a percent, however most are expressed as ">99.0 %". For most equipment capable of operating at >99.0 percent efficiency, there is usually a wide enough variation, that it is not practical to establish a reasonable and representative upper level of control efficiency in tenths of a percent with any certainty.

In the original CARB control technology database, five pollutants were addressed and 95 control technologies were listed. The updated list addresses 12 pollutant types and approximately 350 control technologies and control technology combinations.

The new control technology listing represents an improvement in that the range between low and high control efficiency has been narrowed, in many cases, compared to the previous version. Aside from the incorporation of new data, this is also due to several other reasons:

1. the low end of control efficiency of many pieces of equipment has been increased due to upgrades and more stringent specifications by industry in order to meet more stringent regulations,

2. broad control technology groups have been broken down into more specific types of equipment/applications,

3. the addition of new, higher-efficiency control equipment developed in recent years, and

4. the removal of some devices and/or control efficiency data because they were not deemed to be primary control equipment for the pollutant identified, or no data could be located on the equipment, most likely because the technology is no longer widely-used.

During the study, researchers strived to provide estimates of reasonable upper and lower bounds on the control efficiencies. Whenever possible, these ranges were based on test data, however, in many cases, professional judgement was used to establish a reasonable range. Therefore, the user should be cautioned that, in any given situation, a control technology could achieve efficiencies outside of the estimated range. For assessments dealing with permit review, risk assessment, and other regulatory studies, testing of the source should be required.

CHAPTER I. INTRODUCTION

The California Air Resources Board (CARB) is responsible for compiling a statewide air pollutant emissions inventory and improving the inventory as necessary to meet its objectives and those of its emissions inventory clients (e.g., local air quality districts). As part of this process, CARB requires a comprehensive, up-to-date list of air pollution control technologies that are used for reducing emissions from point sources and the accompanying range of control efficiencies typically achieved for each pollutant. Within this listing, each control technology is assigned a three digit code referred to as a control technology code (CTC).

The current control technology database used by CARB was developed by the United States Environmental Protection Agency (EPA) over 15 years ago for use in the National Emissions Data System (NEDS) and does not include cost data. Due to the age of this listing, a number of new technologies do not appear, or have to be considered as being a part of a much more broad category. In addition, the control efficiency data are outdated or the range is so broad that the information is of limited value. Finally, the existing control data only apply to criteria pollutants. CARB would also like to include information on control of air toxics (however, only a small portion of the resources allocated to this project were to be used in assessing control efficiencies for air toxics).

Point source control technologies for the following air pollutants are addressed in this study:

- three groups of particulate matter - total suspended particulate (TSP) (referred to in this report as simply "PM"), particulate matter less than 10 microns in diameter (PM10), and particulate matter less than 2.5 microns (PM2.5);
- oxides of sulfur (SOx);
- oxides of nitrogen (NOx);
- carbon monoxide (CO);
- total organic gases (TOG) and reactive organic gases (ROG); and
- air toxics grouped into four categories depending on physical and chemical properties - volatile organic toxics (VOT), particulate organic toxics (POT), particulate inorganic toxics (PIT), and gaseous inorganic toxics (GIT).

The methods and data sources used to conduct the control technology research are described in Chapter II. Methods used to assess control efficiencies of air toxics are also outlined in this chapter. Research results, including an overview of control technologies for criteria air pollutants, are presented in Chapter III. A printout of the revised control technology database, including the control technology name and the range of control

efficiencies that can be expected during actual operating conditions, is presented in Appendix A. Control technology descriptions and costs corresponding to the technologies listed in the control technology database are presented in Appendix B. Both California (Assembly Bill 2588) and Federal Clean Air Act Title III air toxics are classified as to toxics type (i.e., VOT, POT, PIT, or GIT) in Appendix C.

CHAPTER II. METHODS AND DATA SOURCES

A. DEVELOPMENT OF POINT SOURCE CONTROL TECHNOLOGY INFORMATION

The point source control technologies database currently in use by CARB and California air districts was developed by EPA over 15 years ago for use in the NEDS. By 1997, this database had become out of date (e.g., newer controls were not represented, ranges of control efficiencies were overly broad). In addition, no information on the cost of control technologies is included in the existing database. To update this listing, a comprehensive review of relevant air pollution data sources was conducted. Among these sources were:

- the EPA's AP-42, Control Technique Guidelines, Alternative Control Technique documents, and other reports on control equipment for criteria and hazardous air pollutants (HAPs, also referred to as air toxics);
- the State and Territorial Air Pollution Program Administrators/Association of Local Air Pollution Control Officials (STAPPA/ALAPCO) control technology reports;
- the California Air Pollution Control Officers' Association's Reasonably Available Control Technology/Best Available Control Technology Clearinghouse;
- standard air pollution references (e.g., the *Air Pollution Engineering Manual*);
- in-house control technology assessments previously prepared by Pechan; and
- recent technical literature including the Air and Waste Management Association (AWMA) technical papers, periodicals, the internet, and telephone contacts (EPA, trade organizations, and manufacturers).

The data gathered from these sources were used in preparing descriptions of each control technology, and establishing the expected control efficiency range and cost effectiveness (annualized cost per ton of pollutant reduced) achieved in practice. Information for most of the commonly-used control technologies were well documented and based on in-depth studies, however, professional judgement was still necessary, especially in establishing control ranges for equipment combinations. Data for less-used and emerging technologies were often sparse and/or vague; professional judgment was applied in establishing efficiency ranges.

Cost effectiveness is expressed in 1995 dollars, unless otherwise noted. When cost effectiveness data in the literature was based on a year earlier than 1995, escalation factors were applied to convert to 1995 dollars. At times, the only available cost data were expressed in units such as dollars/scfm or dollars/megawatt of electricity, and assumptions and professional judgement were necessary to convert to dollars/ton of pollutant reduced. In some cases, costs could not be determined. It should be noted that only 5% of the project

effort was devoted to developing cost data. Actual annualized cost data may vary greatly, depending on the specific case.

The air pollutants addressed in this study include three groups of particulate matter. These are PM (i.e., TSP), PM10, and PM2.5. The other pollutants addressed are SOx, NOx, CO, TOG, ROG, and air toxics (methods for establishing control efficiencies for air toxics are given in the next section).

B. METHODS FOR ASSESSING CONTROL EFFICIENCIES FOR AIR TOXICS

As part of this project, a limited effort was made to include control efficiency data for air toxics. Few controls are in use today that were designed specifically for the control of air toxics. Control of toxics emissions is generally done with technologies originally designed to control criteria pollutants [e.g., volatile organic compounds (VOC) and PM]. These controls are described in Chapter III and Appendix B. One recent exception is the use of carbon injection technology for the control of mercury (Hg) and dioxin/furan emissions from municipal and medical waste incinerators. Additional details on carbon injection can be found in Appendix B.

For the purpose of assigning toxics control efficiencies to the various technologies described in this study, it was necessary to characterize air toxics by the physical and chemical properties that relate to their control (e.g., whether they are an aerosol or gas, organic/inorganic). The first step to accomplish this was to expand the control technology database by an additional eight fields to account for the upper and lower end of the efficiency range for four toxics types:

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

The second step was to assign each air toxic to one or more of the four types described above. Pollutants listed as HAPs under Section 112 of the Clean Air Act and air toxics listed in California's AB2588 program are presented in Appendix C. In some cases, a secondary type 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.

Various criteria were used in the assignment of each toxic to the four toxics types as presented in Appendix C. Among these were previous experience working with emissions of a toxics species, vapor pressure [e.g., >1 millimeters of Hg column @ 20 degrees Celcius (°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 largely 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.

Users should be extremely careful in assigning control efficiencies using the toxics categorization scheme when dealing with toxics that can take on more than one form (see Appendix C). Also, users should consult the technology descriptions or other literature to ascertain whether the control technology is limited to certain species. For example, the carbon injection control technology is listed as having control efficiencies for POT, PIT, and GIT, however these control efficiencies have only been documented for dioxin/furans (i.e., not all POT) and Hg (i.e., not all PIT or GIT).

There are several limitations to the assignment of toxics into the four general types and assumptions of control efficiency. Limitations include the following:

- *inter-species variability within a toxics type*: for example, some organic toxics are more resistant to thermal oxidation than others. Hence, for a given temperature and residence time some toxics will be combusted with a higher efficiency than others. As an illustration, sample groupings of several toxics are shown in Table 1 (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.

- *partitioning between phases and/or elemental forms*: as mentioned above, some toxics can exist as both a gas and an aerosol (particle). Important among these are semi-volatile organics (such as some dioxins/furans and PAHs) and Hg.

Due to these limitations, it is recommended that caution be used in assigning control efficiencies to toxics species, and that the analyst consider use of the lower end of the

reported range for conservatism. Also, for such uses as input to health and ecological risk assessments, test data of the source under consideration should always be used instead of the values in the current database. As more data specific to control of various toxics become available, the database can be updated to reflect this improved data.

Table 1
Sample Air Toxics Grouped by Ease of Destruction

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

(adapted from Pennington, 1996)

CHAPTER III. RESULTS OF CONTROL TECHNOLOGY RESEARCH

A. METHODS OF AIR POLLUTION CONTROL

Methods for controlling air pollution from point sources include add-on controls, process controls, and integrated controls:

1. *Add-on control*: This type of control typically includes a piece of equipment (e.g., a baghouse) that is added to the exhaust stream.

2. *Process control*: A process control involves a change or modification to an industrial process that would result in a reduction in the emissions generated by a process (e.g., a change from top filling of fuels to bottom filling).

3. *Integrated control*: An integrated control is incorporated into the design of the equipment that produces emissions (e.g., a low-NOx burner).

Modifications that are made to change how a product is produced or handled are in the process control category; such as solvent recovery and re-use, change in fuel type, how fuel is stored and delivered, and modifications to storage facilities, such as tanks. Usually, a process control also implies at least some small benefit to the overall system (fuel or product conservation, less toxic exposure for workers, etc.).

Integrated controls are equipment modifications that are made strictly for the purpose of reducing emissions [e.g., burner design, flue gas recirculation (FGR)].

A general discussion of the types of point source control technologies used for criteria pollutants is given below. For more detailed technology descriptions and listings of the references cited, see Appendix B.

B. POINT SOURCE CONTROL EFFICIENCIES

A printout of the revised control technology database is given in Appendix A. The results of this research effort provided a significant expansion in the coverage of point source pollution controls. Some technologies from the existing database were dropped due to inappropriate nomenclature, or because the technology had become obsolete and there were no indications of current usage. Comparisons between the existing and revised control technology databases are given in Table 2.

Table 2
Comparison of Existing and Revised Control Technology Databases

Parameter	Existing Database	Revised Database
Pollutants Covered	PM, VOC, NOx, SOx, CO	PM, PM10, PM2.5, TOG, ROG, CO, NOx, SOx, VOT, POT, PIT, GIT
Add-on Controls	68	106
Process Controls	18	17
Integrated Controls	9	51
Control Combinations	0	181
Total Controls	**95**	**355**

The control efficiencies are presented in order of the primary pollutant that the technology is designed to control. Some technologies incidentally control other pollutants and, where adequate documentation exists, control efficiency ranges are presented. The three-digit codes assigned to each control technology in the database are ordered by control method and primary pollutant controlled as follows:

- **001 - 399** **Add-on Control Technologies**

  001 - 079 PM, PM10, PM2.5
  080 - 159 SOx
  160 - 239 NOx
  240 - 319 TOG, ROG, VOT
  320 - 399 Open

- **400 - 599** **Process Controls**

  400 - 429 PM, PM10, PM2.5
  430 - 449 NOx
  450 - 479 TOG, ROG, VOT
  480 - 599 Open

- **600 - 699** **Integrated Controls**

  600 - 679 NOx
  680 - 699 Open

- **700 - 999** **Control Combinations**

  700 - 749 NOx
  750 - 949 PM, PM10, PM2.5
  921 - 999 Open

In general, control efficiencies are expressed in whole numbers. Some control efficiencies greater than 99 percent are expressed in tenths of a percent, however most are expressed as ">99.0%". For most equipment capable of operating at >99.0 percent efficiency, there is often a wide variation in performance in the 99 to 100 percent range. Therefore, with available data, it is not practical in most cases to establish a representative upper level of control efficiency in tenths of a percent with any certainty. In cases where good data was available to show an upper range of greater than 99.5 percent, this value was selected for use in the database. Similarly when sufficient data showed an upper range in excess of 99.9 percent, this value was selected. Due to the variability for many controls, researchers did not feel that establishing efficiencies with intermediate values (e.g., 99.3, 99.7) was warranted.

For the purpose of this study, the collection efficiency (the amount of emissions delivered to an add-on control device divided by the amount generated by the source, expressed as a percent) is assumed to be 100 percent. That is, the control efficiencies reported are based on the amount of emissions actually treated by the equipment. The control efficiencies also do not reflect a lower bound that could represent "upset conditions" (i.e., all ranges are based on typical operating conditions).

During the study, researchers strived to provide estimates of reasonable upper and lower bounds on the control efficiencies. Whenever possible, these ranges were based on test data, however, in many cases, professional judgement was used to establish a reasonable range. Therefore, the user should be cautioned that, in any given situation, a control technology could achieve efficiencies outside of the estimated range. For assessments dealing with permit review, risk assessment, and other regulatory studies, testing of the source should be required.

C. CONTROL TECHNOLOGY DESCRIPTIONS

Detailed descriptions on control technologies and available cost data are given in Appendix B. The following subsections provide general descriptions of the more common control technologies covered during this study.

1. PM Control Technologies

PM is generated by combustion and other industrial processes. In most cases, PM is collected after it has been generated, hence, virtually all PM controls are add-on controls.

a. Precleaning Devices

Mechanical collectors are a broad class of PM control devices that use either gravity settling and/or inertial impaction mechanisms to remove large and/or dense particles from flue gas streams. Because their performance capability is limited to the removal of large and/or dense particles from gas streams and regulatory requirements have become more stringent, they are now used primarily as pretreatment devices to reduce the PM loading on fabric filters, electrostatic precipitators (ESPs), and scrubbers. However, some types of collectors may provide adequate control of PM for some applications as a stand alone collection device or in series combination.

There is great diversity in the design and operating principles of the various types of mechanical collectors. Mechanical collectors include gravity settling chambers, momentum separators, centrifugal collectors, and single and multiple cyclones.

b. Fabric Filters

Fabric filters are add-on controls that are used in a wide variety of industrial and commercial applications to control primary PM emissions. Fabric filters remove dust from a gas stream by passing the stream through a porous fabric. Fabric filters are frequently referred to as baghouses because the fabric is usually configured in cylindrical bags. When they can be applied to control PM emissions for a particular emission source (i.e., excessive heat or incompatible exhaust constituents are not present), fabric filters are considered to provide superior control of fine PM relative to other control devices (e.g., ESPs and scrubbers).

c. Gravel- or Granular-bed Filters

Gravel-bed filters were developed for use in controlling emissions from high-temperature flue gas streams to remove fine PM and smoke particles. The advantage of the gravel-bed filter relative to a fabric filter is its ability to tolerate high-temperature gas streams containing combustible constituents and/or high moisture contents. The typical set up involves drawing exhaust gas through a bed of pea gravel which traps the PM. The bed is cleaned either continuously or intermittently depending on the design of the unit. They are also used where control of fine PM would require a scrubber to operate at a high pressure drop to obtain the same level of control.

An alternative design of the gravel-bed filter involves the use of a slow, moving bed of granular rock as the filtration medium. To enhance collection efficiency, moving bed filters have been electrostatically charged. Gravel-bed moving filters are also called granular-bed moving filters.

d. Electrostatic Precipitators

ESPs are add-on control devices that are designed to remove PM from the flue gas stream using electrical fields. ESPs may be designed and operated as dry or wet units. Dry units typically are used to control large gas volumes, such as electric utility coal-fired boilers. Wet ESP technology has been developed more recently than dry ESP technology. Wet ESPs are used to control relatively smaller gas volumes than dry ESPs, and on flue gas streams containing fumes or mist which may be difficult to control with a dry ESP or fabric filter.

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. The most common ESP designs are wire-plate and wire-pipe collectors, but rigid frame-plate designs are also used.

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. ESP size is also related to the ratio of the surface

area of the collection electrodes to the gas flow (the specific collection area). Maximizing electric field strength will maximize ESP collection efficiency.

e. Wet Scrubbers

Wet scrubbers are add-on control devices that are used to remove PM from gas by capturing the particles in liquid (usually water) droplets, foam, or bubbles, and separating the droplets from the gas stream. The droplets act as conveyors of the PM out of the gas stream. With wet scrubbers, PM and soluble gases can be removed simultaneously. Wet scrubbers capture PM through three primary mechanisms: (1) *impaction* of the particle directly into a target droplet; (2) *interception* of the particle by the target droplet as the particle nears the droplet; and (3) *diffusion* of the particle through the gas surrounding the target droplet until the particle is close enough to be captured. Other scrubber collection mechanisms include gravitation, electrostatics, and condensation. The dominant means of PM capture in most industrial wet scrubbers is inertial impaction.

Wet scrubbers are classified by the method used to induce the contact between the liquid and the PM. The major categories of wet scrubbers are: spray chamber scrubbers, also referred to as spray towers; packed-bed scrubbers; tray-type scrubbers; mechanically-aided scrubbers; venturi and orifice scrubbers; condensation scrubbers; and charged scrubbers.

Wet scrubbers are used under circumstances where the contaminant cannot be removed easily in a dry form; soluble gases are present; soluble or wettable PM is present; the contaminant will undergo some subsequent wet process (such as recovery, wet separation or settling, or neutralization); the pollution control system must be compact; or where the contaminants are most safely handled wet rather than dry (i.e., where the dry PM may ignite or explode).

f. Mist Eliminators

Mist eliminators are used to eliminate mist (fine liquid droplets) from carrying pollutants out of scrubber stacks; however, they can also be used as stand-alone control devices to control acid mists. There are two general types of mist eliminators: 1) blade-type, consisting of one or more sets of parallel, chevron-shaped baffles (blades), and 2) mesh-pad, which are made up of densely-packed layers of interlocked filaments. The principal control mechanisms are inertial impaction and direct interception.

g. Fluid-Bed Dry Scrubbers

Fluid-bed dry scrubbers are used in the primary aluminum manufacturing industry to control PM emissions from potroom prebake cells and anode baking furnaces. The dry scrubbing system consists of a fluid-bed reactor with a fabric filter located on top of the reactor.

h. Fuel Switching

Fuel switching to avoid generating PM is a potential process control, but has historically been used to control emissions of NOx and sulfur dioxide (SO_2). With the

passage of the revised national ambient air quality standard covering PM2.5, this technology may become more important in controlling PM emissions from combustion sources (e.g., oil-fired boilers). Industrial, commercial, or institutional (ICI) boilers or process heaters burning coal or oil can reduce PM emissions by switching to natural gas. Switching from coal or oil to natural gas may require retrofit of burners.

i. Miscellaneous Controls

Several PM emission controls are generally considered to be area source controls rather than point source controls, however, they are addressed here because of their widespread use. Two controls used to reduce PM emissions from spray painting in spray paint booths include water curtains and mat or panel filters. Water curtains are water sprays through which paint booth emissions are drawn to remove PM. Alternatively, paint booth emissions are controlled using mat or panel filters. Mat or panel filters are similar to air filters used in residential heating and air conditioning systems.

Wet suppression is a temporary measure for controlling fugitive PM emissions from unpaved surfaces, storage piles, and material handling. Typically, liquid sprays of water, a water solution of a chemical agent (a surfactant or a foaming agent), oil, or micron-sized foam are applied to control emissions. Wet suppression controls emissions by agglomeration (i.e., combining small dust particles with larger particles/aggregates or liquid droplets) to prevent or suppress the PM from leaving the surface and becoming airborne.

2. SOx Control Technologies

Sources of SOx emissions include, in decreasing order of significance, fuel combustion for the generation of electricity, fuel combustion for industrial processes, and emissions from metals production. The different grades of coal and oil combusted to provide heat for boilers or industrial processes all contain some fraction of organically-bound sulfur, as well as, in the case of coal, inorganic sulfur as pyrites. These sources of sulfur form SO_2, and, in lesser amounts, sulfur trioxide when heated in the presence of oxygen.

Many nonferrous metals, such as copper, zinc, and lead, are derived from ores containing sulfur compounds, which, when heated, form SO_2. Coke production and the use of coke in the ferrous metals industry also produce SO_2 emissions. Since SO_2 emissions make up 95 percent or more of the total SOx emissions from combustion sources and SOx emissions are commonly expressed as the SO_2 equivalent, SOx and SO_2 are used interchangeably throughout this report.

There are three main approaches to reducing SOx emissions: pre-combustion methods, control during combustion, and post-combustion methods. In-furnace sorbent addition and flue gas desulfurization are add-on controls which attempt to control emissions during and after combustion, respectively. Fuel switching and fuel cleaning are pre-combustion process controls.

a. Flue Gas Desulfurization (FGD)

The largest category of SO_2 control technologies is FGD, where the SO_2 is captured after formation and removed from the waste gas stream. FGD systems fall into several categories, including dry scrubbing, semi-dry scrubbing, and wet scrubbing. These categories can be further divided into non-regenerable and regenerable systems. Most systems introduce the SO_2-containing waste gas flow to a sorbent, as a solution, slurry, or solid, made up of materials which absorb and react with the SO_2. After the sorbent has absorbed and reacted with the SO_2, the spent reagent is either regenerated or disposed. Some processes are designed to yield a spent reagent that is a desirable product for which there is a market, while others must be disposed. Some regenerable processes concentrate the SO_2 and pass it on to one of several processes which produce liquid SO_2, sulfuric acid, or elemental sulfur.

b. In-Furnace Controls

Several combustion processes are being developed which allow reagents to be introduced or injected directly into the burning fuel. These are known as dry sorbent furnace injection and combustion-zone sorbent addition. With these technologies, the aim is to introduce a material which will react with the SO_2, while avoiding the intense heat of the combustion zone which renders many reactive materials ineffective or less effective. The introduction of the sorbent directly to the combustor allows for longer reaction times between the SO_2 and the reagent, and can reduce the complexity of a sorbent injection system.

c. Fuel Switching

In fuel switching, a low-sulfur fuel is used as a replacement for a fuel with a higher sulfur content. Switching from coal to oil or natural gas for power generation or for certain industrial processes was popular before the early 1970's when economic and legislative restrictions made it a less attractive SO_2-reducing technique. However, co-firing of coal and oil with natural gas has been applied in some situations. High- to low-sulfur coal switching remains popular as an SO_2 reduction method, though it is not applicable in all cases due to low-sulfur coal transportation costs, or combustor inflexibility. In some cases, it has been possible to extend the service life of a high-emitting combustion process by adding just enough low-sulfur coal to the established supply of high-sulfur coal, along with some combustor modifications, to achieve a mandated emissions level.

d. Fuel Cleaning

Fuel cleaning methods have been used to reduce the amount of sulfur in coal before it is combusted in order to lower SO_2 emissions. Sulfur exists in coal in two different forms, inorganic and organic, and each requires a different cleaning technique. Inorganic sulfur in the form of pyrites (compounds of sulfur and iron) is found in most coals, and this is removed mainly by physical means. Often, these processes consist of coal being crushed and screened by density or surface property differentiation using water or air. Chemical cleaning, in which the organic sulfur in coal is removed, is still in the development stage, and has not yet been extensively used in commercial applications.

3. NOx Control Technologies

NOx emissions are generated by stationary sources as a product of combustion or as a stack gas product of a chemical reaction in which NOx assumes the role of either one of the reactants or products. Combustion sources are the predominant NOx generators and, consequently, the majority of the control technologies are designed for combustion sources.

Combustion NOx is formed via three basic mechanisms: thermal NOx, fuel NOx, and prompt NOx. Of the three, combustion NOx control addresses thermal and fuel NOx. Prompt NOx is typically short-lived and requires a very fuel-rich flame. Therefore, prompt NOx controls are not addressed.

The formation of NOx by combustion processes is dependent upon four conditions: the concentration of oxygen at the flame, the peak flame temperature, the residence time of the combustion gases at the flame temperature, and the nitrogen content of the fuel. The control of NOx from combustion processes is divided into three different strategies: modifications of the combustion process or equipment (integrated controls), treatment of flue gas (add-on controls), and fuel modification (process control). Techniques used for NOx control are dependent on the mechanism of NOx formation, the point at which the control strategy is initiated within the combustion process, and the emission source configuration.

a. Combustion (Integrated) Controls

Combustion modifications are proven control techniques that reduce thermal NOx formation by modifying the combustion process to quench combustion gases or to lower oxygen availability and shorten residence times at high temperatures. Several types of combustion modifications used for reducing NOx emissions are low excess air firing, over fire air (OFA), and FGR. Combustion modifications such as these, are intended to reduce the formation of NOx during the combustion process by:

1) restricting the availability of combustion oxygen, and/or

2) quenching the combustion flame temperature.

The restriction of combustion oxygen has the potential of providing a reducing environment during the combustion process and lower peak flame temperature, thereby decreasing the formation of both fuel and thermal NOx. However, the use of aggressive combustion modification, while reducing the formation of NOx, can increase the emissions of carbon monoxide and hydrocarbons. Currently, these modifications are being used on sources such as electric utility boilers, commercial and industrial boilers, and glass melting furnaces.

There are other combustion modifications capable of achieving even greater reductions. These include low NOx-burners for boilers and heaters, and pre-stratified charge systems for reciprocating internal combustion engines. These modifications reduce the formation of NOx by precision control of the combustion process through more advanced combustion technologies and are often designed to provide acceptable performance with low NOx formation. Low NOx burners may incorporate different

combustion control technologies such as flue-gas recirculation and staged combustion as well as improved air/fuel mixing capabilities into one design.

The pre-stratified charge technology introduces an air/fuel charge to the combustion chamber of reciprocating internal combustion engines that is stratified into a large-volume, lean-fuel mixture zone and a small-volume, rich-fuel mixture. Upon compression of the stratified charge, the ignition of the rich-mixture zone provides a hot flame front to ignite the lean-fuel mixture. The resulting combustion process has a reduced peak flame temperature with stable combustion at lean-fuel mixtures approaching the lower flammability limit. Combustion modifications can be used independently or in combination with other control technologies.

b. Exhaust (Add-on) Controls

Add-on control techniques that reduce NOx emissions downstream of the combustion zone are also available. These include selective catalytic reduction, selective non-catalytic reduction, non-selective catalytic reduction, and catalytic oxidation/absorption. In the first three technologies, NOx is reduced to nitrogen and water. For catalytic oxidation/absorption, all of the NOx is oxidized to nitrogen dioxide (NO_2) which is then scrubbed from the exhaust.

c. Process Controls

Different fuels produce different amounts of NOx for a given amount of energy released in the combustion process. This is due to differences in methods of combustion and chemical composition, including fuel nitrogen content. Generally, with respect to NOx and other pollutant emissions, natural gas burns cleaner than petroleum distillate fuels, which burn cleaner than residual fuels, which burn cleaner than solid fossil fuels. Fuel switching can be an effective method of emission reduction for many applications.

4. CO Control Technologies

Good combustion practices on combustion point sources are assumed and are not considered an air pollution control method for this study. Add-on technologies, such as catalytic and non-catalytic oxidizers (see next section) are assumed to control CO emissions with the same efficiency as VOC.

5. TOG and ROG Control Technologies

Most control efficiency data found in the literature are related to the control of VOCs, which are a component of TOG. VOCs include all organic compounds with appreciable vapor pressures. Except for methane, ethane and a number of halogenated compounds identified by EPA as non-reactive, CARB considers all organic gases to be reactive; or ROG. Virtually all of the reviewed literature sources on control equipment simply refers to the group of VOC, ROG, and TOG as VOC. Hence, the control efficiency ranges for TOG and ROG presented in this report are assumed to be equivalent to the VOC ranges reported in the literature. Many VOC species are toxic and are referred to in this report as VOT (described further in the air toxics section below).

In cases where information is available on non-chlorinated VOCs and chlorinated VOCs (CVOCs), this is presented in the description of the specific control equipment presented in Appendix B. In cases where a piece of equipment is capable of destroying both, the control efficiency of the non-chlorinated VOC is typically at the upper end of the range and the CVOC destruction efficiency is at the lower end of the range.

a. Add-on Controls

There are four basic types of add-on controls used to control VOCs: combustion, adsorption, condensation, and absorption. Several new technologies use innovative variations of these basic methods.

Combustion- Combustion, also referred to as oxidation or incineration, is used to destroy VOCs; hence another term for control efficiency by combustion is destruction efficiency. Complete combustion depends on an adequate supply of oxygen, sufficiently high temperature to ignite the waste-fuel mixture, turbulent mixing of the waste-fuel, and sufficient residence time for the reaction to occur.

Devices which use straight combustion to destroy VOC include direct flame thermal oxidizers (incinerators, afterburners) and flares. Because of economics, most combustion devices employ some type of heat recovery to transfer heat from the exhaust gas to the entering waste gas. This is usually in the form of a heat exchanger. Thermal oxidizers so equipped may also be described as "recuperative." Another class of oxidizing equipment known as regenerative thermal oxidizers use a high-density media (e.g., ceramic-packed bed) still hot from a previous cycle to preheat the incoming VOC-laden stream.

Some oxidizers use a catalyst to increase the rate of reaction, reduce the temperature required to produce complete combustion, and reduce the required reactor volume. Most thermal oxidizer designs also have a catalytic counterpart, such as catalytic oxidizers, regenerative catalytic oxidizers, and fluidized bed catalytic oxidizers. Catalytic combustion devices also typically use some type of heat recovery.

Adsorption- Adsorption occurs when organic molecules are captured on the surface of a micro-porous solid such as activated carbon. Adsorption may be physical and/or chemical. Other suitable media (adsorbents) include hydrophobic zeolites, silicates, aluminas, aluminosilicates (molecular sieves), and synthetic resins. These substances have a very porous structure, and with their large exposed surface, can take up appreciable volumes of various gases. The extent of adsorption can be increased further by "activating" the adsorbents in various ways. Activation removes impurities and exposes a larger free surface for potential adsorption. Activated carbon is the most widely used adsorbent.

An adsorption device is typically a two-bed system. VOC-laden air is passed through one bed at a time and treated. Over time, the pore spaces begin to fill. To maintain constant high efficiency, the bed is taken offline and the gas shifted to the other bed before saturation (or "breakthrough") occurs.

Typically, the saturated bed is regenerated, or desorbed with steam. The effluent-steam mixture can be condensed, and, if there is sufficient value, the solvent can be recovered by decanting and/or distillation. The bed may also be desorbed by reducing the

pressure (vacuum desorption). In some cases, the spent adsorbent may be replaced and regenerated offsite.

Condensation- Condensation is the process of converting a gas to a liquid. This is typically accomplished by lowering the temperature. Condensers are simple devices that normally use water for cooling, but may use other heat-exchange media (e.g., chlorinated fluorocarbons). Condensers may be indirect ("surface condensers") or direct contact. In surface condensers, the cooling medium and vapor/condensate are separated by a surface area (e.g., shell and tube). In direct contact condensers, the vapors and cooling medium are intimately mixed and combined. Typical contact condenser types are barometric and jet. The disadvantage of contact condensers is that the condensate cannot be reused and further treatment or separation may be necessary. Most condensers used in air pollution control are surface condensers.

In refrigerated condenser systems, mechanical refrigeration is used for cooling. These systems include a refrigeration unit, a heat exchanger/evaporator, storage for the chilled and defrost brines, and a surface condenser. Cryogenic condensers use the cooling value of liquid nitrogen in a surface 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. Cryogenic condensation is best suited to industries that already use significant quantities of liquid nitrogen in their normal processes for inerting, blanketing, and purging.

Absorption- Absorption is used for VOCs and inorganic gases. It is, however, more commonly employed for inorganic gases [e.g., hydrogen sulfide, ammonia (NH_3), chlorides, and fluorides] than for organic vapors.

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 components 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 and for relatively high VOC concentrations [approximately 1,000 parts per million by volume (ppmv) and higher] of readily water soluble organics (most alcohols, ethylene oxide, organic acids, aldehydes, ketones, amines, and glycols).

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.

New Add-on Control Technologies- The first example of a commonly-employed new technology for VOC control is biofiltration. The mechanism of biofiltration includes a combination of adsorption, absorption, and microbial degradation. Vapor-phase organic

contaminants are passed through a bed of biologically active material, (primarily mixtures based on soil, compost, or peat) and sorb to the material surface, where they are degraded by microorganisms in the material.

Another example of a new VOC technology is ozonation with enhanced carbon adsorption. This technology is an enhanced carbon adsorption system that combines wet scrubbing, carbon adsorption, and ozone reaction to remove organic vapors from an airstream.

The third new VOC technology is ozonation with catalytic oxidation. This gaseous ozonation system employs a catalytic reactor to oxidize VOCs using small amounts of ozone at relatively low temperatures (160 to 220 °F).

Another new technology is flameless thermal oxidation (FTO). FTO is used for destroying VOCs in process and waste stream off-gas treatment and in the treatment of VOCs and CVOCs from off-gases from soil remediation. FTO uses a heated packed-bed reactor filled with inert ceramic pieces maintained at 1,600 to 1,850 °F. The packed bed generates a uniform thermal reaction zone where oxidation of organic compounds occurs and flame propagation is prevented.

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 HEC reactor is a glass tube filled with glass beads. A high-voltage electrode is located along the centerline of the reactor.

Silent Discharge Plasma Technology (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.

In photocatalytic oxidation, VOCs or CVOCs are trapped on the surface of a proprietary catalytic adsorbent. The trapped contaminants are catalytically destroyed (oxidized) by ultra-violet light on the adsorbent, which continuously regenerates the adsorbent.

b. Process Controls

Depending on the process, certain modifications can be effective in controlling VOCs. These include substituting materials to low or no-VOC types, changing the methods by which organic liquids are applied, stored and transferred, and making other operational changes.

6. AIR TOXICS CONTROL TECHNOLOGIES

As previously mentioned, a limited effort was made to include control efficiency data for air toxics. Nearly all of the control technologies in use for control of air toxics were originally designed to control VOC or PM and are described in the appropriate sections above and in Appendix B. To provide the control technology user with a sense of the potential for control of air toxics, a method was outlined in Chapter II to estimate the potential for control of individual toxics using a VOC or PM10 control method.

Researchers included a relatively new technology, carbon injection, in the database that was specifically-designed to control emissions of Hg. This add-on technology is being used in municipal and medical waste incinerators to control both Hg and dioxin/furan emissions (see Appendix B for more details).

REFERENCES

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

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

Bartikowski, 1997. B. Bartikowski, Basys Technologies (800-254-5525), personal communication with E. Albright, E.H. Pechan & Associates, Inc., December 3, 1997.

Belco, 1997. Belco Technologies Corp., personal contact with Tom Walker (973) 884-4700, Parsippany, NJ, December 23, 1997.

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

Carr, 1994. F. Housely Carr, "Scrubbers Going Through a Phase," ENR, Vol. 233, No. 1, July 4, 1994.

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

Clean Air Act Information Network, NOx Controls for Existing Utility Boilers by Bill Neuffer.

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.

Danziger, 1997. Danziger, R; *et al.*; *The SCONOx Catalytic Absorption System for Power Generation: Full-Scale Operational Results;* Presentation; Power-Gen Asia '97; 11 September 1997.

REFERENCES (Continued)

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.

Dennis, 1993. R.A. Dennis, N.W.J. Ford, and M.J. Cooke, "A Guide to Flue Gas Desulphurization for the Industrial Plant Manager," from "Desulfurization 3," Institution of Chemical Engineers Symposium Series No. 131, Warwickshire, UK, 1993.)

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.

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, 1978. U.S. Environmental Protection Agency, *Fugitive Emissions from Integrated Iron and Steel Plants*, EPA-600/2-78-050, Washington, DC, March 1978.

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, 1984. U.S. Environmental Protection Agency, Industrial Environmental Research Laboratory, "The Current Status of Commercial Utility Flue Gas Desulfurization Systems," Research Triangle Park, NC, February 1984.

EPA, 1985. U.S. Environmental Protection Agency, *Flue Gas Conditioning*, EPA-600/7-85-005, NTIS PB85-173912, Research Triangle Park, NC, February 1985.

REFERENCES (Continued)

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, 1991. 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, 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, 1992b. U.S. Environmental Protection Agency, Office of Research and Development, "Facility Pollution Prevention Guide," EPA/600/R-92/088, Washington, DC, May 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, 1992d. 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, 1993a. U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards; "Alternative Control Techniques Document – NOx Emissions from Stationary Gas Turbines," Research Triangle Park, NC, January 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, 1993c. 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, 1993d. U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards; "Alternative Control Techniques Document – NOx Emissions from Process Heaters," Research Triangle Park, NC, September 1993.

REFERENCES (Continued)

EPA, 1994a. 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, 1994b. U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards; "Alternative Control Techniques Document – NOx Emissions from Glass Manufacturing", Research Triangle Park, NC, June 1994.

EPA, 1994c. U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards; "Alternative Control Techniques Document – NOx Emissions from Iron and Steel Mills", Research Triangle Park, NC, September 1994.

EPA, 1994d. U.S. Environmental Protection Agency, National PM Study: OPPE Particulate Programs Implementation Evaluation System, Office of Policy, Planning, and Evaluation, Washington DC, September 1994.

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

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

EPA, 1996b. U.S. Environmental Protection Agency, "Estimating and Controlling Fugitive Lead Emissions from Industrial Sources," EPA-452/R-96-006, Research Triangle Park, NC, May 1996.

EPA, 1997a. U.S. Environmental Protection Agency, "The Emission Reduction And Cost Analysis Model for NOx (ERCAM -- NOx)," September 1997 (Note: This is a draft document).

EPA, 1997b. U.S. Environmental Protection Agency, "Compilation of Air Pollutant Emission Factors, Volume I, Stationary Point and Area Sources," AP-42, Fifth Edition, Research Triangle Park, NC, October 1997.

Friedman, 1981. L.J. Friedman, "Production of Liquid SO_2, Sulfur and Sulfuric Acid," Sulfur Dioxide Control in Pyrometallurgy, edited by T.D. Chatwin and N. Kikumoto, Metallurgical Society of AIME, Warrendale, PA, February 1981.

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.

REFERENCES (Continued)

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.

Hart, 1997. B. Hart, Comprehensive Environmental Solutions, (415-669-1111), personal communication with E. Albright, E.H. Pechan & Associates, Inc., December 3, 1997.

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.

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

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

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

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.

Lurgi, 1997. Personal communication with Ron Triscori (201-967-3191) of Lurgi Corp, Paramus, NJ, December 29, 1997.

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.

REFERENCES (Continued)

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

Pechan, 1988. E.H. Pechan & Associates, Inc., "National Assessment of VOC, CO, and NO_x Controls, Emissions, and Costs," prepared for U.S. Environmental Protection Agency, Office of Policy Planning and Evaluation, Washington, DC, September 1988.

Pechan, 1995. E.H. Pechan & Associates, Inc., "Development of Control Cost Equations for Particulate Matter," Final Report, Prepared for U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Research Triangle Park, NC, September 1995.

Pechan, 1997. E.H. Pechan & Associates, Inc., "Clean Air Act Section 812 Prospective Cost Analysis -- Draft Report," prepared for Industrial Economics, Inc., Cambridge, MA, September 1997.

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

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.

Radcliffe, 1992. Paul Radcliffe, "FGD Economics," EPRI Journal, Vol. 17, No. 6, September 1992.

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.

REFERENCES (Continued)

Roeck, 1996. Douglas R. Roeck and Alfred Sigg, "Carbon Injection Proves Effective in Removing Dioxins," from Environmental Protection, January 1996.

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.

Siebel, 1976. U.S. Department of the Interior, *Dust Control at a Transfer Point Using Foam and Water Sprays*, Publication No. TPR 97, Bureau of Mines, Washington, DC, 1976.

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, 1993. State and Territorial Air Pollution Program Administrators and Association of Local Air Pollution Control Officials, "Meeting the 15-Percent Rate-of-Progress Requirement Under the Clean Air Act: A Menu of Options," September 1993.

REFERENCES (Continued)

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, D.C., 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, "A 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.

REFERENCES (Continued)

WGA, 1988. Western Governors Association, "Western States Acid Deposition Project Phase II: Technical Feasibility and Cost of Obtaining Further Reductions in SO_2 and NOx Emissions from Existing and New Sources, Volume I," Denver, CO, Revised February 1988.

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

Zinc, 1997. John C. Zinc, Ph.D., ED., "Retrofit Burners," Power Engineering, November 1997.

ACRONYMS AND ABBREVIATIONS

AIRS/FS	Aerometric Information Retrieval System/ Facility Subsystem
AWMA	Air and Waste Management Association
BOOS	burner out of service
BTEX	benzene, toluene, ethylbenzene, and total xylenes
°C	degrees Celsius
CARB	California Air Resources Board
CEC	control efficiency code
cfm	cubic feet per minute
cm	centimeter
CO	carbon monoxide
CEC	Control Equipment Code
CTC	Control Technology Code
CVOC	chlorinated volatile organic compound
DESP	dry electrostatic precipitator
DMA	dimethylanaline
DOE	United States Department of Energy
EPA	United States Environmental Protection Agency
EPRI	Electric Power Research Institute
ESP	electrostatic precipitator
°F	degrees Fahrenheit
FBCI	fluidized bed catalytic incineration
FGD	flue gas desulfurization
FGR	flue gas recirculation
FTO	flameless thermal oxidation
GIT	gaseous inorganic toxic
HAPs	hazardous air pollutants
HCl	hydrogen chloride gas or hydrochloric acid
HEC	High Energy Corona
Hg	mercury
hr	hour
ICI	industrial, commercial, and institutional
in	inch
lb	pound
LEA	low excess air
LEC	low emission combustion
LEL	lower explosive limit
LNB	low NOx burners
MEK	methyl ethyl ketone
MMBtu	million British thermal units
NAAQS	National Ambient Air Quality Standards
NEDS	National Emissions Data System

(Continued)

ACRONYMS AND ABBREVIATIONS (Continued)

NH_3	ammonia
NO_2	nitrogen dioxide
NOx	oxides of nitrogen
NSCR	non-selective catalytic reduction
OFA	over fire air
Pechan	E.H. Pechan & Associates, Inc.
PAH	polycyclic aromatic hydrocarbon
PCE	perchloroethylene
PIT	particulate inorganic toxic
PM	particulate matter (total)
PM10	particulate matter less then 10 microns in diameter
PM2.5	particulate matter less then 2.5 microns in diameter
POT	particulate organic toxic
ppm	parts per million
ppmv	parts per million by volume
psi	pounds per square inch
ROG	reactive organic gas
RTO	regenerative thermal oxidation
RCO	regenerative catalytic oxidizer
scfm	standard cubic feet per minute
SCR	selective catalytic reduction
SDPT	Silent Discharge Plasma Technology
SNCR	selective noncatalytic control reduction
SO_2	sulfur dioxide
SOx	oxides of sulfur
STAPPA/ALAPCO	State and Territorial Air Pollution Program Administrators and Association of Local Air Pollution Control Officials
SVE	soil vapor extraction
TCE	trichloroethylene
TNMOG	total nonmethane organic gases
TOG	total organic gases
TSP	total suspended particulate
μm	micrometers
VOC	volatile organic compound
VOL	volatile organic liquid
VOT	volatile organic toxic

APPENDIX A: CONTROL TECHNOLOGY DATABASE

APPENDIX A: CONTROL TECHNOLOGY DATABASE

The control technologies are identified by a three-digit CTC and are ordered by control method and primary pollutant controlled. For reference purposes, the old Control Equipment Code (CEC) from the previous published Turnaround Document (TAD) Manual for each CTC, where applicable. Additional information on the control efficiency ranges, applications, and cost effectiveness is presented in Appendix B. Data on the classification of air toxics (i.e., VOT, POT, PIT, and GIT) are presented in Appendix C.

001 - 399 Add-on Control Technologies

001 - 079	PM, PM10, PM2.5
080 - 159	SOx
160 - 239	NOx
240 - 319	TOG, ROG, VOT
320 - 399	Open

400 - 599 Process Controls

400 - 429	PM, PM10, PM2.5
430 - 449	NOx
450 - 479	TOG, ROG, VOT
480 - 599	Open

600 - 699 Integrated Controls

600 - 679	NOx
680 - 699	Open

700 - 999 Control Combinations

700 - 749	NOx
750 - 949	PM, PM10, PM2.5

Where;

750 - 767	Gravity Collector + Other
768 - 784	Momentum Separator + Other
785 - 802	Centrifugal Collector + Other
803 - 844	Single Cyclone + Other
845 - 870	Multiple Cyclone + Other
871 - 880	ESP + Other
881 - 891	Fabric Filter + Other
892 - 915	Wet scrubber Combinations
916 - 920	Mist Eliminator Combinations
921 - 999	Open

The control efficiencies assigned to the four categories (i.e., VOT, POT, PIT, and GIT) are largely 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.

Users should be extremely careful in assigning control efficiencies using the toxics categorization scheme when dealing with toxics that can take on more than one form (see Appendix C). Also, users should consult the technology descriptions in Appendix B or other literature to ascertain whether the control technology is limited to certain species. For example, the carbon injection control technology is listed as having control efficiencies for POT, PIT, and GIT, however these control efficiencies have only been documented for dioxin/furans (i.e., not all POT) and Hg (i.e., not all PIT or GIT).

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Appendix A: Control Technology Code Numbers and Normal Control Efficiency Range

CTC	CONTROL DEVICE/METHOD	OLD CEC	PM Low	PM High	PM10 Low	PM10 High	PM2.5 Low	PM2.5 High	SOx Low	SOx High	NOx Low	NOx High	CO Low	CO High
	ADD-ON CONTROLS:													
001	Wet Scrubber (General, Not Classified)	001	55	> 99.9	55	> 99.9	25.0	97.0	50	> 99.0				
002	Electrostatic Precipitator (Dry)	010	90	> 99.9	85	99.5	80.0	> 99.0						
003	Electrostatic Precipitator (Dry) with Flue Gas Conditioning	NEW	90	> 99.9	85	99.5	80.0	> 99.0						
004	Electrostatic Precipitator (Wet)	NEW	80	> 99.9	75	99.5	70.0	> 99.0						
005	Fabric Filter (Pulse-jet, Reverse-air, Mechanical Shaker)	016	90	> 99.9	85	> 99.9	80.0	99.9	15	30.0				
006	Venturi or Orifice Scrubber	053	90	> 99.0	70	> 99.0	25.0	99.0	80	> 99.0				
007	Single Cyclone (conventional)	075	70	90.0	30	90.0	0.0	40.0						
008	Single Cyclone (high efficiency)	075	80	99.0	60	95.0	20.0	70.0						
009	Single Cyclone (high throughput)	075	80	99.0	10	40.0	0.0	10.0						
010	Multiple Cyclone w/o Fly Ash Reinjection	076	80	99.0	50	95.0	20.0	70.0						
011	Multiple Cyclone w/ Fly Ash Reinjection	077	70	99.0	35	85.0	20.0	60.0						
012	Mist Eliminator - Blade Type	014	80	98.0	80	98.0	50.0	70.0						
013	Mist Eliminator - Mesh-Type	015	95	> 99.0	95	> 99.0	90.0	99.0						
014	Spray Chamber Wet Scrubber (Spray Tower, Mist Scrubber, Cyclonic Spray Tower, Vane-type Cyclonic Tower)	052	70	> 99.5	70	99.0	25.0	97.0	80	> 99.0				
015	Gravity Collector (Settling Chamber)	004, 005, 006	10	99.0										

Appendix A: Control Technology Code Numbers and Normal Control Efficiency Range

CTC	CONTROL DEVICE/METHOD	OLD CEC	TOG Low	TOG High	ROG Low	ROG High	VOT Low	VOT High	POT Low	POT High	PIT Low	PIT High	GIT Low	GIT High
	ADD-ON CONTROLS:													
001	Wet Scrubber (General, Not Classified)	001							55	> 99.9	55	> 99.9		
002	Electrostatic Precipitator (Dry)	010							85	99.5	85	99.5		
003	Electrostatic Precipitator (Dry) with Flue Gas Conditioning	NEW							85	99.5	85	99.5		
004	Electrostatic Precipitator (Wet)	NEW	50.0	70.0	50.0	70.0	50.0	70.0	75	99.5	75	99.5		
005	Fabric Filter (Pulse-jet, Reverse-air, Mechanical Shaker)	016							85	> 99.9	85	> 99.9		
006	Venturi or Orifice Scrubber	053							70	> 99.0	70	> 99.0		
007	Single Cyclone (conventional)	075							30	90.0	30	90.0		
008	Single Cyclone (high efficiency)	075							60	95.0	60	95.0		
009	Single Cyclone (high throughput)	075							10	40.0	10	40.0		
010	Multiple Cyclone w/o Fly Ash Reinjection	076							50	95.0	50	95.0		
011	Multiple Cyclone w/ Fly Ash Reinjection	077							35	85.0	35	85.0		
012	Mist Eliminator - Blade Type	014							80	98.0	80	98.0		
013	Mist Eliminator - Mesh-Type	015							95	> 99.0	95	> 99.0		
014	Spray Chamber Wet Scrubber (Spray Tower, Mist Scrubber, Cyclonic Spray Tower, Vane-type Cyclonic Tower)	052	50	95.0	50	95.0	50	95.0	70	99.0	70	99.0	85	> 99.0
015	Gravity Collector (Settling Chamber)	004, 005, 006												

Appendix A: Control Technology Code Numbers and Normal Control Efficiency Range

CTC	CONTROL DEVICE/METHOD	OLD CEC	PM Low	PM High	PM10 Low	PM10 High	PM2.5 Low	PM2.5 High	SOx Low	SOx High	NOx Low	NOx High	CO Low	CO High
016	Centrifugal Collector (Mechanically-aided Separator or Dry Dynamic Separator)	007, 008, 009, 056	30	99.0	0	10.0	0.0	5.0						
017	Momentum Separator	NEW	30	99.0	0	10.0	0.0	5.0						
018	Tray-Type Scrubber [Impingement Plate, Perforated Plate, Horizontal Impingement-Plate (Baffle)]	055	55	99.0	55	99.0	25.0	97.0	80	> 99.0				
019	Mat or Panel Filter	058	10	98.0	10	90.0								
020	Gravel Bed Filter	063	90	> 99.5	85	99.0	80.0	99.0						
021	Gravel Bed Moving Filter	063	80	95.0	70	90.0								
022	Gravel Bed Moving Filter - Electrostatically Augmented	NEW	80	> 99.0	70	95.0								
023	Mechanically-Aided Scrubber	001	70	> 99.0	70	99.0	25.0	97.0						
024	Condensation Scrubber	001	90	> 99.0	70	> 99.0	25.0	99.0						
025	Charged Scrubber	001	90	> 99.0	70	> 99.0	25.0	99.0						
026	Packed-Bed Scrubber (Fiber-Bed, Moving-Bed, Cross-Flow, Grid-Packed)	001	85	> 99.0	85	99.0	25.0	97.0						
027	Fluid-Bed Dry Scrubber	071	90	> 99.9	85	> 99.9	80.0	99.9						
028	Dust Suppression by Water Sprays	061	30	99.0	30	95.0	30	90.0						
029	Dust Suppression by Chemical Stabilizers or Wetting Agents	062	30	99.0	30	95.0	30	90.0						
030	Water Curtain	086	10	95.0										
031	Chemical Fume Suppressants for Electroplating and Anodizing Tanks	NEW	99	99.9	99	99.9	95.0	99.0						

Appendix A: Control Technology Code Numbers and Normal Control Efficiency Range

			TOG		ROG		VOT		POT		PIT		GIT	
CTC	CONTROL DEVICE/METHOD	OLD CEC	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
016	Centrifugal Collector (Mechanically-aided Separator or Dry Dynamic Separator)	007, 008, 009, 056							0	10.0	0	10.0		
017	Momentum Separator	NEW							0	10.0	0	10.0		
018	Tray-Type Scrubber [Impingement Plate, Perforated Plate, Horizontal Impingement-Plate (Baffle)]	055							55	99.0	55	99.0		
019	Mat or Panel Filter	058							10	90.0	10	90.0		
020	Gravel Bed Filter	063							85	99.0	85	99.0		
021	Gravel Bed Moving Filter	063							70	90.0	70	90.0		
022	Gravel Bed Moving Filter - Electrostatically Augmented	NEW							70	95.0	70	95.0		
023	Mechanically-Aided Scrubber	001							70	99.0	70	99.0		
024	Condensation Scrubber	001							70	> 99.0	70	> 99.0		
025	Charged Scrubber	001							70	> 99.0	70	> 99.0		
026	Packed-Bed Scrubber (Fiber-Bed, Moving-Bed, Cross-Flow, Grid-Packed)	001							85	99.0	85	99.0		
027	Fluid-Bed Dry Scrubber	071	80	90.0	80	90.0	80	90.0	85	> 99.9	85	> 99.9		
028	Dust Suppression by Water Sprays	061												
029	Dust Suppression by Chemical Stabilizers or Wetting Agents	062												
030	Water Curtain	086												
031	Chemical Fume Suppressants for Electroplating and Anodizing Tanks	NEW									99	99.9		

Appendix A: Control Technology Code Numbers and Normal Control Efficiency Range

CTC	CONTROL DEVICE/METHOD	OLD CEC	PM Low	PM High	PM10 Low	PM10 High	PM2.5 Low	PM2.5 High	SOx Low	SOx High	NOx Low	NOx High	CO Low	CO High
032	Plastic Balls for Electroplating Tanks	NEW	50	80.0	50	80.0	20.0	50.0						
080	Gas Scrubber (general, not classified)	013							20	> 99.0				
081	Wellman-Lord/Sodium Sulfite Scrubbing	034							90	> 99.0				
082	Magnesium Oxide Scrubbing	035							85	> 99.0				
083	Dual Alkali Scrubbing	036							85	95.0				
084	Citrate Process Scrubbing	037							90	99.0				
085	Ammonia Scrubbing	038							90	95.0				
086	Catalytic Oxidation - Flue Gas Desulfurization	039							90	99.0				
087	Dry Sorbent Duct Injection	041							50	80.0				
088	Circulating Dry Scrubbing	041							70	90.0				
089	Wet Sorbent Injection/Spray Drying	042							30	90.0				
090	Sulfuric Acid Plant - Contact Process	043							95	98.0				
091	Sulfuric Acid Plant - Double Contact Process	044							98	> 99.0				
092	Claus Process Sulfur Plant, without Tail Gas Treatment	045							95	99.0				
093	Claus Process Sulfur Plant, with Tail Gas Treatment	045							98	> 99.0				
094	Adsorption: various adsorbents, including activated carbon, zeolites, molecular sieves, silicates, aluminas, and synthetic resins	048							70	80.0				
095	Adsorption: copper oxide	NEW							80	90.0				

Appendix A: Control Technology Code Numbers and Normal Control Efficiency Range

CTC	CONTROL DEVICE/METHOD	OLD CEC	TOG Low	TOG High	ROG Low	ROG High	VOT Low	VOT High	POT Low	POT High	PIT Low	PIT High	GIT Low	GIT High
032	Plastic Balls for Electroplating Tanks	NEW									50	80.0		
080	Gas Scrubber (general, not classified)	013											85	> 99.0
081	Wellman-Lord/Sodium Sulfite Scrubbing	034												
082	Magnesium Oxide Scrubbing	035												
083	Dual Alkali Scrubbing	036												
084	Citrate Process Scrubbing	037												
085	Ammonia Scrubbing	038												
086	Catalytic Oxidation - Flue Gas Desulfurization	039												
087	Dry Sorbent Duct Injection	041												
088	Circulating Dry Scrubbing	041												
089	Wet Sorbent Injection/Spray Drying	042												
090	Sulfuric Acid Plant - Contact Process	043												
091	Sulfuric Acid Plant - Double Contact Process	044												
092	Claus Process Sulfur Plant, without Tail Gas Treatment	045												
093	Claus Process Sulfur Plant, with Tail Gas Treatment	045												
094	Adsorption: various adsorbents, including activated carbon, zeolites, molecular sieves, silicates, aluminas, and synthetic resins	048	90	> 99.0	90	> 99.0	90	> 99.0					90	> 99.0
095	Adsorption: copper oxide	NEW												

Appendix A: Control Technology Code Numbers and Normal Control Efficiency Range

CTC	CONTROL DEVICE/METHOD	OLD CEC	PM Low	PM High	PM10 Low	PM10 High	PM2.5 Low	PM2.5 High	SOx Low	SOx High	NOx Low	NOx High	CO Low	CO High
096	Packed Column - Gas Absorption	050							80	> 99.0				
097	Tray-Type Gas Absorption Column (NOx data for adipic and nitric acid process)	051							80	> 99.0	85	97.0		
098	Wet Lime/Limestone Slurry Scrubbing	067							60	98.0				
099	Alkaline Fly Ash Scrubbing	068							50	95.0				
100	Sodium Carbonate Scrubbing	069							80	98.0				
101	Sodium Hydroxide Scrubbing	070							70	95.0				
102	Dimethylaniline Scrubbing	NEW							95	99.0				
103	Hydrogen Peroxide Scrubbing	NEW							90	99.0				
104	Seawater Scrubbing	001							85	98.0				
105	Dry Sorbent Furnace Injection without Duct Humidification	041							20	70.0				
106	Dry Sorbent Furnace Injection with Duct Humidification	041							40	90.0				
107	Combustion-Zone Sorbent Addition	041							15	90.0				
160	Selective Non-Catalytic Reduction, Annealing Furnace	032									25	60.0		
161	Selective Non-Catalytic Reduction, Glass Furnace	032									30	60.0		
162	Selective Non-Catalytic Reduction, Industrial & Commercial Boiler, Gas	032									30	60.0		
163	Selective Non-Catalytic Reduction, Industrial & Commercial Boiler, Coal/Oil	032									30	70.0		
164	Selective Non-Catalytic Reduction, Cement Kiln, Precalciner	032									30	70.0		

Appendix A: Control Technology Code Numbers and Normal Control Efficiency Range

CTC	CONTROL DEVICE/METHOD	OLD CEC	TOG Low	TOG High	ROG Low	ROG High	VOT Low	VOT High	POT Low	POT High	PIT Low	PIT High	GIT Low	GIT High
096	Packed Column - Gas Absorption	050	70	> 99.0	70	> 99.0	70	> 99.0					85	> 99.0
097	Tray-Type Gas Absorption Column (NOx data for adipic and nitric acid process)	051	70	> 99.0	70	> 99.0	70	> 99.0					85	> 99.0
098	Wet Lime/Limestone Slurry Scrubbing	067												
099	Alkaline Fly Ash Scrubbing	068												
100	Sodium Carbonate Scrubbing	069												
101	Sodium Hydroxide Scrubbing	070												
102	Dimethylaniline Scrubbing	NEW												
103	Hydrogen Peroxide Scrubbing	NEW												
104	Seawater Scrubbing	001												
105	Dry Sorbent Furnace Injection without Duct Humidification	041												
106	Dry Sorbent Furnace Injection with Duct Humidification	041												
107	Combustion-Zone Sorbent Addition	041												
160	Selective Non-Catalytic Reduction, Annealing Furnace	032												
161	Selective Non-Catalytic Reduction, Glass Furnace	032												
162	Selective Non-Catalytic Reduction, Industrial & Commercial Boiler, Gas	032												
163	Selective Non-Catalytic Reduction, Industrial & Commercial Boiler, Coal/Oil	032												
164	Selective Non-Catalytic Reduction, Cement Kiln, Precalciner	032												

Appendix A: Control Technology Code Numbers and Normal Control Efficiency Range

CTC	CONTROL DEVICE/METHOD	OLD CEC	PM Low	PM High	PM10 Low	PM10 High	PM2.5 Low	PM2.5 High	SOx Low	SOx High	NOx Low	NOx High	CO Low	CO High
165	Selective Non-Catalytic Reduction, Process Heaters, Gas	032									20	50.0		
166	Selective Non-Catalytic Reduction, Process Heaters, Residual/Distillate Oil	032									30	60.0		
167	Selective Non-Catalytic Reduction, Utility Boiler, Coal	032									30	60.0		
168	Selective Non-Catalytic Reduction, Utility Boiler, Oil or Gas	032									35	50.0		
169	Selective Catalytic Reduction, Glass Furnace	065									70	80.0		
170	Selective Catalytic Reduction, Annealing Furnace	065									70	90.0		
171	Selective Catalytic Reduction, Industrial & Commercial Boiler	065									80	90.0		
172	Selective Catalytic Reduction, Utility Boiler, Oil or Gas	065									50	95.0		
173	Selective Catalytic Reduction, Lean Burn Diesel or Dual Fuels	065									80	90.0		
174	Selective Catalytic Reduction, Cement Kiln	065									80	90.0		
175	Selective Catalytic Reduction, Nitric Acid Process	065									85	95.0		
176	Selective Catalytic Reduction, Process Heaters, Residual Oil	065									75	90.0		
177	Selective Catalytic Reduction, Process Heaters, Distillate Oil	065									80	90.0		
178	Selective Catalytic Reduction, Process Heaters, Gas	065									80	90.0		
179	Selective Catalytic Reduction, Utility Boiler, Coal	065									60	90.0		
180	Non-Selective Catalytic Reduction, Rich Burn Gas	065									90	95.0		
181	Non-Selective Catalytic Reduction, Nitric Acid Process	065									95	> 99.0		
182	Non-Selective Catalytic Oxidation and Absorption, Gas Turbine	065									99	> 99.0		

Appendix A: Control Technology Code Numbers and Normal Control Efficiency Range

CTC	CONTROL DEVICE/METHOD	OLD CEC	TOG Low	TOG High	ROG Low	ROG High	VOT Low	VOT High	POT Low	POT High	PIT Low	PIT High	GIT Low	GIT High
165	Selective Non-Catalytic Reduction, Process Heaters, Gas	032												
166	Selective Non-Catalytic Reduction, Process Heaters, Residual/Distillate Oil	032												
167	Selective Non-Catalytic Reduction, Utility Boiler, Coal	032												
168	Selective Non-Catalytic Reduction, Utility Boiler, Oil or Gas	032												
169	Selective Catalytic Reduction, Glass Furnace	065												
170	Selective Catalytic Reduction, Annealing Furnace	065												
171	Selective Catalytic Reduction, Industrial & Commercial Boiler	065												
172	Selective Catalytic Reduction, Utility Boiler, Oil or Gas	065												
173	Selective Catalytic Reduction, Lean Burn Diesel or Dual Fuels	065												
174	Selective Catalytic Reduction, Cement Kiln	065												
175	Selective Catalytic Reduction, Nitric Acid Process	065												
176	Selective Catalytic Reduction, Process Heaters, Residual Oil	065												
177	Selective Catalytic Reduction, Process Heaters, Distillate Oil	065												
178	Selective Catalytic Reduction, Process Heaters, Gas	065												
179	Selective Catalytic Reduction, Utility Boiler, Coal	065												
180	Non-Selective Catalytic Reduction, Rich Burn Gas	065												
181	Non-Selective Catalytic Reduction, Nitric Acid Process	065												
182	Non-Selective Catalytic Oxidation and Absorption, Gas Turbine	065												

Appendix A: Control Technology Code Numbers and Normal Control Efficiency Range

			PM		PM10		PM2.5		SOx		NOx		CO	
CTC	CONTROL DEVICE/METHOD	OLD CEC	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
183	Thermal Reduction, Adipic Acid	NEW									70	95.0		
240	Catalytic Oxidizer	019 020	25	> 99.0	25	> 99.0							90	99.0
241	Direct Flame Thermal Oxidizer	021 022	25	> 99.0	25	> 99.0							95	> 99.0
242	Flaring	023	25	98.0	25	98.0							98	> 99.0
243	Regenerative Thermal Oxidizer	NEW	25	> 99.0	25	> 99.0							95	> 99.0
244	Regenerative Catalytic Oxidizer	NEW	25	> 99.0	25	> 99.0							90	99.0
245	Fluidized Bed Catalytic Incineration	NEW	25	> 99.0	25	> 99.0							70	> 99.0
246	Flameless Thermal Oxidation	NEW	25	> 99.0	25	> 99.0							99	> 99.0
247	High Energy Corona	NEW											90	> 99.0
248	Silent Discharge Plasma Technology	NEW											95	99.0
249	Photocatalytic Oxidation	NEW											95	> 99.0
250	Ozonation - Catalytic Oxidation	082												
251	Ozonation - Enhanced Carbon Adsorption	082												
252	Biofiltration	NEW												
253	Cryogenic Condensation	NEW												
254	Water blanket	NEW												
255	Vapor Recovery System (Stage I) - Bulk Terminals	047												
256	Vapor Recovery System (Stage I) - Bulk Plants	047												

Appendix A: Control Technology Code Numbers and Normal Control Efficiency Range

			TOG			ROG			VOT			POT			PIT		GIT	
CTC	CONTROL DEVICE/METHOD	OLD CEC	Low		High	Low		High	Low		High	Low		High	Low	High	Low	High
183	Thermal Reduction, Adipic Acid	NEW																
240	Catalytic Oxidizer	019 020	90		99.0	90		99.0	90		99.0	90		99.0				
241	Direct Flame Thermal Oxidizer	021 022	95	>	99.0	95	>	99.0	95	>	99.0	95	>	99.0				
242	Flaring	023	98	>	99.0	98	>	99.0	98	>	99.0	98	>	99.0				
243	Regenerative Thermal Oxidizer	NEW	95	>	99.0	95	>	99.0	95	>	99.0	95	>	99.0				
244	Regenerative Catalytic Oxidizer	NEW	90		99.0	90		99.0	90		99.0	90		99.0				
245	Fluidized Bed Catalytic Incineration	NEW	70	>	99.0	70	>	99.0	70	>	99.0	70	>	99.0				
246	Flameless Thermal Oxidation	NEW	99	>	99.0	99	>	99.0	99	>	99.0	99	>	99.0				
247	High Energy Corona	NEW	90	>	99.0	90	>	99.0	90	>	99.0							
248	Silent Discharge Plasma Technology	NEW	95		99.0	95		99.0	95		99.0							
249	Photocatalytic Oxidation	NEW	95	>	99.0	95	>	99.0	95	>	99.0							
250	Ozonation - Catalytic Oxidation	082	95	>	99.0	95	>	99.0	95	>	99.0							
251	Ozonation - Enhanced Carbon Adsorption	082	95	>	99.0	95	>	99.0	95	>	99.0							
252	Biofiltration	NEW	75		99.0	75		99.0	75		99.0							
253	Cryogenic Condensation	NEW	95	>	99.0	95	>	99.0	95	>	99.0							
254	Water blanket	NEW	90	>	99.0	90	>	99.0	90	>	99.0							
255	Vapor Recovery System (Stage I) - Bulk Terminals	047	95		99.0	95		99.0	95		99.0							
256	Vapor Recovery System (Stage I) - Bulk Plants	047	90		95.0	90		95.0	90		95.0							

Appendix A: Control Technology Code Numbers and Normal Control Efficiency Range

CTC	CONTROL DEVICE/METHOD	OLD CEC	PM Low		PM High	PM10 Low		PM10 High	PM2.5 Low		PM2.5 High	SOx Low		SOx High	NOx Low	NOx High	CO Low	CO High
257	Tube and Shell Condenser	072																
258	Refrigerated Condenser	073																
259	Contact Condensers	074																
320	Carbon Injection	NEW																
399	Miscellaneous Add-on Control Devices	099	-		-	-		-	-		-	-		-	-	-	-	-
	PROCESS CONTROLS:																	
400	Fuel Switching: High Sulfur Coal to Low Sulfur Coal	NEW										50		90.0				
401	Fuel Switching: Coal to No. 4 and Distillate Oil	NEW	90	>	99.0	80		99.0	70.0		99.0	0		90.0	0	90.0	0	90.0
402	Fuel Switching: Coal to Natural Gas	NEW	98	>	99.0	98	>	99.0	98.0	>	99.0	98	>	99.0	30	90.0	30	98.0
403	Fuel Switching: Residual Oil to Distillate Oil	NEW	60	>	99.0	80	>	99.0	80.0	>	99.0	60		98.0	0	70.0	0	80.0
404	Fuel Switching: Oil to Natural Gas	NEW	90	>	99.0	80	>	99.0	50.0	>	99.0	98	>	99.0	30	80.0	30	90.0
405	Coal Cleaning	NEW										10		40.0				
431	Electric Boost, Glass Manufacturing	NEW													10	25.0		
432	Cullet Preheat, Glass Manufacturing	NEW													5	25.0		
450	Inert Gas Blanketing	087																
451	Conversion to Variable Vapor Space Tank	090																
452	Conversion to Floating Roof Tank	091																
453	Conversion to Pressurized Tank	092																

Appendix A: Control Technology Code Numbers and Normal Control Efficiency Range

CTC	CONTROL DEVICE/METHOD	OLD CEC	TOG Low	TOG High	ROG Low	ROG High	VOT Low	VOT High	POT Low	POT High	PIT Low	PIT High	GIT Low	GIT High
257	Tube and Shell Condenser	072	50	90.0	50	90.0	50	90.0						
258	Refrigerated Condenser	073	50	95.0	50	95.0	50	95.0						
259	Contact Condensers	074	50	90.0	50	90.0	50	90.0						
320	Carbon Injection	NEW					95	> 99.0	95	> 99.0			95	> 99.0
399	Miscellaneous Add-on Control Devices	099	-	-	-	-	-	-	-	-	-	-	-	-
	PROCESS CONTROLS:													
400	Fuel Switching: High Sulfur Coal to Low Sulfur Coal	NEW												
401	Fuel Switching: Coal to No. 4 and Distillate Oil	NEW							80	99.0	80	99.0		
402	Fuel Switching: Coal to Natural Gas	NEW							98	> 99.0	98	> 99.0		
403	Fuel Switching: Residual Oil to Distillate Oil	NEW							80	> 99.0	80	> 99.0		
404	Fuel Switching: Oil to Natural Gas	NEW							80	> 99.0	80	> 99.0		
405	Coal Cleaning	NEW												
431	Electric Boost, Glass Manufacturing	NEW												
432	Cullet Preheat, Glass Manufacturing	NEW												
450	Inert Gas Blanketing	087	90	98.0	90	98.0	90	98.0						
451	Conversion to Variable Vapor Space Tank	090	10	> 99.0	10	> 99.0	10	> 99.0						
452	Conversion to Floating Roof Tank	091	60	99.0	60	99.0	60	99.0						
453	Conversion to Pressurized Tank	092	95	> 99.0	95	> 99.0	95	> 99.0						

Appendix A: Control Technology Code Numbers and Normal Control Efficiency Range

CTC	CONTROL DEVICE/METHOD	OLD CEC	PM Low	PM High	PM10 Low	PM10 High	PM2.5 Low	PM2.5 High	SOx Low	SOx High	NOx Low	NOx High	CO Low	CO High
454	Submerged/Bottom Filling	089 093												
455	Underground Tank	094												
456	White Paint	095												
457	Process Change	046							10	90.0				
599	Miscellaneous Process Controls	099	-	-	-	-	-	-	-	-	-	-	-	-
	INTEGRATED CONTROLS:													
600	Low NOx Burners, Process Heaters, Gas	024									30	60.0		
601	Low NOx Burners, Process Heaters, Residual Oil	024									30	60.0		
602	Low NOx Burners, Utility Boiler, Coal	024									20	50.0		
603	Low NOx Burners, Utility Boiler, Oil or Gas	024									30	50.0		
604	Low NOx Burners, Cement Kiln, Mid-kiln firing	024									20	40.0		
605	Dry Low NOx Combustor, Gas Turbine	024									60	90.0		
606	Staged Combustion	025									20	60.0		
607	Staged Combustion, Cement Kiln	025									30	45.0		
608	Flue Gas Recirculation	026									20	70.0		
609	Flue Gas Recirculation, Industrial & Commercial Boiler, Coal	026									20	45.0		
610	Flue Gas Recirculation, Industrial & Commercial Boiler, Oil	026									15	30.0		
611	Flue Gas Recirculation, Industrial & Commercial Boiler, Gas	026									50	65.0		

Appendix A: Control Technology Code Numbers and Normal Control Efficiency Range

CTC	CONTROL DEVICE/METHOD	OLD CEC	TOG Low	TOG High	ROG Low	ROG High	VOT Low	VOT High	POT Low	POT High	PIT Low	PIT High	GIT Low	GIT High
454	Submerged/Bottom Filling	089 093	10	60.0	10	60.0	10	60.0						
455	Underground Tank	094	98	> 99.0	98	> 99.0	98	> 99.0						
456	White Paint	095	0	30.0	0	30.0	0	30.0						
457	Process Change	046	10	> 99.0	10	> 99.0	10	> 99.0						
599	Miscellaneous Process Controls	099	-	-	-	-	-	-	-	-	-	-	-	-
	INTEGRATED CONTROLS:													
600	Low NOx Burners, Process Heaters, Gas	024												
601	Low NOx Burners, Process Heaters, Residual Oil	024												
602	Low NOx Burners, Utility Boiler, Coal	024												
603	Low NOx Burners, Utility Boiler, Oil or Gas	024												
604	Low NOx Burners, Cement Kiln, Mid-kiln firing	024												
605	Dry Low NOx Combustor, Gas Turbine	024												
606	Staged Combustion	025												
607	Staged Combustion, Cement Kiln	025												
608	Flue Gas Recirculation	026												
609	Flue Gas Recirculation, Industrial & Commercial Boiler, Coal	026												
610	Flue Gas Recirculation, Industrial & Commercial Boiler, Oil	026												
611	Flue Gas Recirculation, Industrial & Commercial Boiler, Gas	026												

Appendix A: Control Technology Code Numbers and Normal Control Efficiency Range

CTC	CONTROL DEVICE/METHOD	OLD CEC	PM Low	PM High	PM10 Low	PM10 High	PM2.5 Low	PM2.5 High	SOx Low	SOx High	NOx Low	NOx High	CO Low	CO High
612	Flue Gas Recirculation, Process Heaters, Oil	026									30	50.0		
613	Flue Gas Recirculation, Process Heaters, Gas	026									50	60.0		
614	Flue Gas Recirculation, Utility Boiler, Coal	026									20	45.0		
615	Flue Gas Recirculation, Utility Boiler, Oil or Gas	026									40	50.0		
616	Low Excess Air, Steel Reheat Furnace	029									10	15.0		
617	Low Excess Air, Industrial & Commercial Boiler, Oil	029									5	25.0		
618	Low Excess Air, Industrial & Commercial Boiler, Coal	029									5	30.0		
619	Low Excess Air, Industrial & Commercial Boiler, Gas	029									5	35.0		
620	Low Excess Air, Process Heaters, Oil	029									5	20.0		
621	Low Excess Air, Process Heaters, Gas	029									5	20.0		
622	Low Excess Air, Utility Boiler, Coal	029									10	20.0		
623	Low Excess Air, Utility Boiler, Oil or Gas	029									10	25.0		
624	Over Fire Air, Industrial & Commercial Boiler, Coal	033									15	30.0		
625	Over Fire Air, Industrial & Commercial Boiler, Gas or Oil	033									20	40.0		
626	Over Fire Air, Utility Boiler, Oil or Gas	033									15	45.0		
627	Over Fire Air, Utility Boiler, Coal	033									15	30.0		
628	Low Emission Combustion, Lean Burn Dual Fuels	NEW									60	80.0		
629	Low Emission Combustion, Rich Burn Gas	NEW									70	90.0		

Appendix A: Control Technology Code Numbers and Normal Control Efficiency Range

CTC	CONTROL DEVICE/METHOD	OLD CEC	TOG Low	TOG High	ROG Low	ROG High	VOT Low	VOT High	POT Low	POT High	PIT Low	PIT High	GIT Low	GIT High
612	Flue Gas Recirculation, Process Heaters, Oil	026												
613	Flue Gas Recirculation, Process Heaters, Gas	026												
614	Flue Gas Recirculation, Utility Boiler, Coal	026												
615	Flue Gas Recirculation, Utility Boiler, Oil or Gas	026												
616	Low Excess Air, Steel Reheat Furnace	029												
617	Low Excess Air, Industrial & Commercial Boiler, Oil	029												
618	Low Excess Air, Industrial & Commercial Boiler, Coal	029												
619	Low Excess Air, Industrial & Commercial Boiler, Gas	029												
620	Low Excess Air, Process Heaters, Oil	029												
621	Low Excess Air, Process Heaters, Gas	029												
622	Low Excess Air, Utility Boiler, Coal	029												
623	Low Excess Air, Utility Boiler, Oil or Gas	029												
624	Over Fire Air, Industrial & Commercial Boiler, Coal	033												
625	Over Fire Air, Industrial & Commercial Boiler, Gas or Oil	033												
626	Over Fire Air, Utility Boiler, Oil or Gas	033												
627	Over Fire Air, Utility Boiler, Coal	033												
628	Low Emission Combustion, Lean Burn Dual Fuels	NEW												
629	Low Emission Combustion, Rich Burn Gas	NEW												

Appendix A: Control Technology Code Numbers and Normal Control Efficiency Range

			PM		PM10		PM2.5		SOx		NOx		CO	
CTC	CONTROL DEVICE/METHOD	OLD CEC	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
630	Low Emission Combustion, Lean Burn Gas	NEW									80	90.0		
631	Ignition Timing Retard, Rich Burn Gas	NEW									0	40.0		
632	Ignition Timing Retard, Lean Burn Gas	NEW									0	20.0		
633	Ignition Timing Retard, Lean Burn Diesel	033									20	30.0		
634	Ignition Timing Retard, Lean Burn Dual Fuels	033									20	30.0		
635	Air-Fuel Ratio Adjustment, Internal Combustion Engines	033									5	40.0		
636	Prestratified Charge Combustion	NEW									80	90.0		
637	Burner Out of Service, Utility Boiler, Coal	NEW									10	20.0		
638	Burner Out of Service, Utility Boiler, Oil or Gas	NEW									15	35.0		
639	Burner Out of Service, Industrial & Commercial Boiler, Coal, Oil or Gas	NEW									10	30.0		
640	Natural Gas Reburn, Industrial & Commercial Boiler, Coal	NEW									25	60.0		
641	Natural Gas Reburn, Industrial & Commercial Boiler, Oil	NEW									15	35.0		
642	Natural Gas Reburn, Utility Boiler, Coal	NEW									25	60.0		
643	Oxygen Firing, Glass Furnace	NEW									80	90.0		
644	Radiant Burners, Process Heaters, Gas	NEW									80	90.0		
645	Radiant Burners, Industrial & Commercial Boiler, Gas	NEW									70	90.0		
646	Water/Steam Injection, Oil, Industrial & Commercial Boiler	028									15	35.0		
647	Water/Steam Injection, Gas, Industrial & Commercial Boiler	028									25	50.0		

Appendix A: Control Technology Code Numbers and Normal Control Efficiency Range

CTC	CONTROL DEVICE/METHOD	OLD CEC	TOG Low	TOG High	ROG Low	ROG High	VOT Low	VOT High	POT Low	POT High	PIT Low	PIT High	GIT Low	GIT High
630	Low Emission Combustion, Lean Burn Gas	NEW												
631	Ignition Timing Retard, Rich Burn Gas	NEW												
632	Ignition Timing Retard, Lean Burn Gas	NEW												
633	Ignition Timing Retard, Lean Burn Diesel	033												
634	Ignition Timing Retard, Lean Burn Dual Fuels	033												
635	Air-Fuel Ratio Adjustment, Internal Combustion Engines	033												
636	Prestratified Charge Combustion	NEW												
637	Burner Out of Service, Utility Boiler, Coal	NEW												
638	Burner Out of Service, Utility Boiler, Oil or Gas	NEW												
639	Burner Out of Service, Industrial & Commercial Boiler, Coal, Oil or Gas	NEW												
640	Natural Gas Reburn, Industrial & Commercial Boiler, Coal	NEW												
641	Natural Gas Reburn, Industrial & Commercial Boiler, Oil	NEW												
642	Natural Gas Reburn, Utility Boiler, Coal	NEW												
643	Oxygen Firing, Glass Furnace	NEW												
644	Radiant Burners, Process Heaters, Gas	NEW												
645	Radiant Burners, Industrial & Commercial Boiler, Gas	NEW												
646	Water/Steam Injection, Oil, Industrial & Commercial Boiler	028												
647	Water/Steam Injection, Gas, Industrial & Commercial Boiler	028												

Appendix A: Control Technology Code Numbers and Normal Control Efficiency Range

CTC	CONTROL DEVICE/METHOD	OLD CEC	PM Low	PM High	PM10 Low	PM10 High	PM2.5 Low	PM2.5 High	SOx Low	SOx High	NOx Low	NOx High	CO Low	CO High
648	Water/Steam Injection, Gas, Gas Turbine	028									55	95.0		
649	Water/Steam Injection, Distillate Oil, Gas Turbine	028									65	95.0		
699	Miscellaneous Integrated Controls	099	-	-	-	-	-	-	-	-	-	-	-	-
	CONTROL COMBINATIONS													
	NOx Controls:													
700	Low NOx Burners + Flue Gas Recirculation, Steel Furnace	NEW									55	80.0		
701	Low NOx Burner + Over Fire Air, Utility Boiler, Coal	NEW									30	70.0		
702	Low NOx Burner + Over Fire Air, Utility Boiler, Oil or Gas	NEW									40	60.0		
703	Low NOx Burners + Selective Catalytic Reduction, Annealing Furnace	NEW									70	95.0		
704	Low NOx Burners + Selective Non-Catalytic Reduction, Annealing Furnace	NEW									60	80.0		
705	Low NOx Burners + Over Fire Air + Selective Catalytic Reduction, Utility Boiler, Coal	NEW									80	95.0		
706	Water/Steam Injection + Selective Catalytic Reduction, Gas Turbine	NEW									60	95.0		
707	Air/Fuel Adjustment + Ignition Timing Retard, Rich Burn Gas	NEW									10	40.0		
708	Selective Non-Catalytic Reduction + Selective Catalytic Reduction, Utility Boiler, Gas/Oil	NEW									70	90.0		
709	Selective Non-Catalytic Reduction + Selective Catalytic Reduction, Utility Boiler, Coal	NEW									80	95.0		
	PM Controls:													
750	2 Gravity Collectors	NEW	10.0	> 99.0										

Appendix A: Control Technology Code Numbers and Normal Control Efficiency Range

CTC	CONTROL DEVICE/METHOD	OLD CEC	TOG Low	TOG High	ROG Low	ROG High	VOT Low	VOT High	POT Low	POT High	PIT Low	PIT High	GIT Low	GIT High
648	Water/Steam Injection, Gas, Gas Turbine	028												
649	Water/Steam Injection, Distillate Oil, Gas Turbine	028												
699	Miscellaneous Integrated Controls	099	-	-	-	-	-	-	-	-	-	-	-	-
	CONTROL COMBINATIONS													
	NOx Controls:													
700	Low NOx Burners + Flue Gas Recirculation, Steel Furnace	NEW												
701	Low NOx Burner + Over Fire Air, Utility Boiler, Coal	NEW												
702	Low NOx Burner + Over Fire Air, Utility Boiler, Oil or Gas	NEW												
703	Low NOx Burners + Selective Catalytic Reduction, Annealing Furnace	NEW												
704	Low NOx Burners + Selective Non-Catalytic Reduction, Annealing Furnace	NEW												
705	Low NOx Burners + Over Fire Air + Selective Catalytic Reduction, Utility Boiler, Coal	NEW												
706	Water/Steam Injection + Selective Catalytic Reduction, Gas Turbine	NEW												
707	Air/Fuel Adjustment + Ignition Timing Retard, Rich Burn Gas	NEW												
708	Selective Non-Catalytic Reduction + Selective Catalytic Reduction, Utility Boiler, Gas/Oil	NEW												
709	Selective Non-Catalytic Reduction + Selective Catalytic Reduction, Utility Boiler, Coal	NEW												
	PM Controls:													
750	2 Gravity Collectors	NEW												

Appendix A: Control Technology Code Numbers and Normal Control Efficiency Range

CTC	CONTROL DEVICE/METHOD	OLD CEC	PM Low		PM High	PM10 Low	PM10 High	PM2.5 Low	PM2.5 High	SOx Low	SOx High	NOx Low	NOx High	CO Low	CO High
751	Gravity Collector + Momentum Separator	NEW	30.0	>	99.0	10.0	30.0	5.0	10.0						
752	Gravity Collector + Centrifugal Collector	NEW	30.0	>	99.0	10.0	30.0	5.0	10.0						
753	Gravity Collector + Single Cyclone (Conventional)	NEW	70.0		99.0	30.0	90.0	0.0	40.0						
754	Gravity Collector + Single Cyclone (High Efficiency)	NEW	80.0		99.0	60.0	95.0	20.0	70.0						
755	Gravity Collector + Single Cyclone (High Throughput)	NEW	80.0		99.0	10.0	40.0	0.0	10.0						
756	Gravity Collector + Wet Scrubber (General)	NEW	55.0	>	99.9	55.0	> 99.9	25.0	97.0						
757	Gravity Collector + Tray-Type Scrubber	NEW	55.0		99.9	55.0	99.9	25.0	97.0						
758	Gravity Collector + Spray Chamber	NEW	70.0		99.9	70.0	99.9	25.0	97.0						
759	Gravity Collector + Mechanically-Aided Scrubber	NEW	70.0		99.9	70.0	99.9	25.0	97.0						
760	Gravity Collector + Packed-Bed Scrubber	NEW	85.0	>	99.9	85.0	> 99.9	25.0	97.0						
761	Gravity Collector + Venturi or Orifice Scrubber	NEW	90.0	>	99.9	90.0	> 99.9	25.0	> 99.0						
762	Gravity Collector + Condensation Scrubber	NEW	90.0	>	99.9	90.0	> 99.9	25.0	> 99.0						
763	Gravity Collector + Charged Scrubber	NEW	90.0	>	99.9	90.0	> 99.9	25.0	> 99.0						
764	Gravity Collector + Electrostatic Precipitator (Dry)	NEW	90.0	>	99.9	85.0	99.5	80.0	> 99.0						
765	Gravity Collector + Electrostatic Precipitator (Wet)	NEW	80.0	>	99.9	75.0	99.5	70.0	> 99.0						
766	Gravity Collector + Fabric Filter	NEW	90.0	>	99.9	85.0	> 99.9	80.0	99.9						
767	Gravity Collector + Gravel Bed Filter	NEW	90.0	>	99.5	85.0	99.0	80.0	99.0						
768	2 Momentum Separators	NEW	30.0	>	99.9	10.0	30.0	5.0	10.0						

Appendix A: Control Technology Code Numbers and Normal Control Efficiency Range

CTC	CONTROL DEVICE/METHOD	OLD CEC	TOG Low	TOG High	ROG Low	ROG High	VOT Low	VOT High	POT Low	POT High	PIT Low	PIT High	GIT Low	GIT High
751	Gravity Collector + Momentum Separator	NEW							10.0	30.0	10.0	30.0		
752	Gravity Collector + Centrifugal Collector	NEW							10.0	30.0	10.0	30.0		
753	Gravity Collector + Single Cyclone (Conventional)	NEW							30.0	90.0	30.0	90.0		
754	Gravity Collector + Single Cyclone (High Efficiency)	NEW							60.0	95.0	60.0	95.0		
755	Gravity Collector + Single Cyclone (High Throughput)	NEW							10.0	40.0	10.0	40.0		
756	Gravity Collector + Wet Scrubber (General)	NEW							55.0	> 99.9	55.0	> 99.9		
757	Gravity Collector + Tray-Type Scrubber	NEW							55.0	99.9	55.0	99.9		
758	Gravity Collector + Spray Chamber	NEW							70.0	99.9	70.0	99.9		
759	Gravity Collector + Mechanically-Aided Scrubber	NEW							70.0	99.9	70.0	99.9		
760	Gravity Collector + Packed-Bed Scrubber	NEW							85.0	> 99.9	85.0	> 99.9		
761	Gravity Collector + Venturi or Orifice Scrubber	NEW							90.0	> 99.9	90.0	> 99.9		
762	Gravity Collector + Condensation Scrubber	NEW							90.0	> 99.9	90.0	> 99.9		
763	Gravity Collector + Charged Scrubber	NEW							90.0	> 99.9	90.0	> 99.9		
764	Gravity Collector + Electrostatic Precipitator (Dry)	NEW							85.0	99.5	85.0	99.5		
765	Gravity Collector + Electrostatic Precipitator (Wet)	NEW	50.0	70.0	50.0	70.0	50.0	70.0	75.0	99.5	75.0	99.5		
766	Gravity Collector + Fabric Filter	NEW							85.0	> 99.9	85.0	> 99.9		
767	Gravity Collector + Gravel Bed Filter	NEW							85.0	99.0	85.0	99.0		
768	2 Momentum Separators	NEW							10.0	30.0	10.0	30.0		

Appendix A: Control Technology Code Numbers and Normal Control Efficiency Range

			PM		PM10		PM2.5		SOx		NOx		CO	
CTC	CONTROL DEVICE/METHOD	OLD CEC	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
769	Momentum Separator + Centrifugal Collector	NEW	30.0	> 99.9	10.0	30.0	5.0	10.0						
770	Momentum Separator + Single Cyclone (Conventional)	NEW	70.0	99.0	30.0	90.0	0.0	40.0						
771	Momentum Separator + Single Cyclone (High Efficiency)	NEW	80.0	99.0	60.0	95.0	20.0	70.0						
772	Momentum Separator + Single Cyclone (High Throughput)	NEW	80.0	99.0	10.0	40.0	0.0	10.0						
773	Momentum Separator + Wet Scrubber (General)	NEW	55.0	> 99.9	55.0	> 99.0	25.0	97.0						
774	Momentum Separator + Tray-Type Scrubber	NEW	55.0	99.9	55.0	99.9	25.0	97.0						
775	Momentum Separator + Spray Chamber	NEW	70.0	99.9	70.0	99.9	25.0	97.0						
776	Momentum Separator + Mechanically-Aided Scrubber	NEW	70.0	99.9	70.0	99.9	25.0	97.0						
777	Momentum Separator + Packed-Bed Scrubber	NEW	85.0	> 99.9	85.0	> 99.9	25.0	97.0						
778	Momentum Separator + Venturi or Orifice Scrubber	NEW	90.0	> 99.9	90.0	> 99.9	25.0	> 99.0						
779	Momentum Separator + Condensation Scrubber	NEW	90.0	> 99.9	90.0	> 99.9	25.0	> 99.0						
780	Momentum Separator + Charged Scrubber	NEW	90.0	> 99.9	90.0	> 99.9	25.0	> 99.0						
781	Momentum Separator + Electrostatic Precipitator (Dry)	NEW	90.0	> 99.9	85.0	99.5	80.0	> 99.0						
782	Momentum Separator + Electrostatic Precipitator (Wet)	NEW	80.0	> 99.9	75.0	99.5	70.0	> 99.0						
783	Momentum Separator + Fabric Filter	NEW	90.0	> 99.9	85.0	> 99.9	80.0	99.9						
784	Momentum Separator + Gravel Bed Filter	NEW	90.0	> 99.5	85.0	99.0	80.0	99.0						
785	2 Centrifugal Collectors	NEW	30.0	> 99.9	10.0	30.0	5.0	10.0						
786	Centrifugal Collector + Blade-Type Mist Eliminator	NEW	80.0	99.0	80.0	98.0	50.0	70.0						

Appendix A: Control Technology Code Numbers and Normal Control Efficiency Range

			TOG		ROG		VOT		POT		PIT		GIT	
CTC	CONTROL DEVICE/METHOD	OLD CEC	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
769	Momentum Separator + Centrifugal Collector	NEW							10.0	30.0	10.0	30.0		
770	Momentum Separator + Single Cyclone (Conventional)	NEW							30.0	90.0	30.0	90.0		
771	Momentum Separator + Single Cyclone (High Efficiency)	NEW							60.0	95.0	60.0	95.0		
772	Momentum Separator + Single Cyclone (High Throughput)	NEW							10.0	40.0	10.0	40.0		
773	Momentum Separator + Wet Scrubber (General)	NEW							55.0	> 99.0	55.0	> 99.0		
774	Momentum Separator + Tray-Type Scrubber	NEW							55.0	99.9	55.0	99.9		
775	Momentum Separator + Spray Chamber	NEW							70.0	99.9	70.0	99.9		
776	Momentum Separator + Mechanically-Aided Scrubber	NEW							70.0	99.9	70.0	99.9		
777	Momentum Separator + Packed-Bed Scrubber	NEW							85.0	> 99.9	85.0	> 99.9		
778	Momentum Separator + Venturi or Orifice Scrubber	NEW							90.0	> 99.9	90.0	> 99.9		
779	Momentum Separator + Condensation Scrubber	NEW							90.0	> 99.9	90.0	> 99.9		
780	Momentum Separator + Charged Scrubber	NEW							90.0	> 99.9	90.0	> 99.9		
781	Momentum Separator + Electrostatic Precipitator (Dry)	NEW							85.0	99.5	85.0	99.5		
782	Momentum Separator + Electrostatic Precipitator (Wet)	NEW	50.0	70.0	50.0	70.0	50.0	70.0	75.0	99.5	75.0	99.5		
783	Momentum Separator + Fabric Filter	NEW							85.0	> 99.9	85.0	> 99.9		
784	Momentum Separator + Gravel Bed Filter	NEW							85.0	99.0	85.0	99.0		
785	2 Centrifugal Collectors	NEW							10.0	30.0	10.0	30.0		
786	Centrifugal Collector + Blade-Type Mist Eliminator	NEW							80.0	98.0	80.0	98.0		

Appendix A: Control Technology Code Numbers and Normal Control Efficiency Range

			PM			PM10			PM2.5			SOx			NOx			CO		
CTC	CONTROL DEVICE/METHOD	OLD CEC	Low		High	Low		High	Low		High	Low		High	Low		High	Low		High
787	Centrifugal Collector + Mesh-Type Mist Eliminator	NEW	95.0	>	99.5	95.0	>	99.5	90.0		99.0									
788	Centrifugal Collector + Single Cyclone (Conventional)	NEW	70.0		99.0	30.0		90.0	0.0		40.0									
789	Centrifugal Collector + Single Cyclone (High Efficiency)	NEW	80.0		99.0	60.0		95.0	20.0		70.0									
790	Centrifugal Collector + Single Cyclone (High Throughput)	NEW	80.0		99.0	10.0		40.0	0.0		10.0									
791	Centrifugal Collector + Wet Scrubber (General)	NEW	55.0	>	99.9	55.0	>	99.0	25.0		97.0									
792	Centrifugal Collector + Tray-Type Scrubber	NEW	55.0		99.9	55.0		99.9	25.0		97.0									
793	Centrifugal Collector + Spray Chamber	NEW	70.0		99.9	70.0		99.9	25.0		97.0									
794	Centrifugal Collector + Mechanically-Aided Scrubber	NEW	70.0		99.9	70.0		99.9	25.0		97.0									
795	Centrifugal Collector + Packed-Bed Scrubber	NEW	85.0	>	99.9	85.0	>	99.9	25.0		97.0									
796	Centrifugal Collector + Venturi or Orifice Scrubber	NEW	90.0	>	99.9	90.0	>	99.9	25.0	>	99.0									
797	Centrifugal Collector + Condensation Scrubber	NEW	90.0	>	99.9	90.0	>	99.9	25.0	>	99.0									
798	Centrifugal Collector + Charged Scrubber	NEW	90.0	>	99.9	90.0	>	99.9	25.0	>	99.0									
799	Centrifugal Collector + Electrostatic Precipitator (Dry)	NEW	90.0	>	99.9	85.0		99.5	80.0	>	99.0									
800	Centrifugal Collector + Electrostatic Precipitator (Wet)	NEW	80.0	>	99.9	75.0		99.5	70.0	>	99.0									
801	Centrifugal Collector + Fabric Filter	NEW	90.0	>	99.9	85.0	>	99.9	80.0		99.9									
802	Centrifugal Collector + Gravel Bed Filter	NEW	90.0	>	99.5	85.0		99.0	80.0		99.0									
803	2 Single Cyclones (Conventional)	NEW	70.0		99.0	30.0		90.0	0.0		40.0									
804	Single Cyclone (Conventional) + Single Cyclone (High Efficiency)	NEW	80.0		99.0	60.0		95.0	20.0		70.0									

Appendix A: Control Technology Code Numbers and Normal Control Efficiency Range

CTC	CONTROL DEVICE/METHOD	OLD CEC	TOG Low	TOG High	ROG Low	ROG High	VOT Low	VOT High	POT Low	POT High	PIT Low	PIT High	GIT Low	GIT High
787	Centrifugal Collector + Mesh-Type Mist Eliminator	NEW							95.0	> 99.5	95.0	> 99.5		
788	Centrifugal Collector + Single Cyclone (Conventional)	NEW							30.0	90.0	30.0	90.0		
789	Centrifugal Collector + Single Cyclone (High Efficiency)	NEW							60.0	95.0	60.0	95.0		
790	Centrifugal Collector + Single Cyclone (High Throughput)	NEW							10.0	40.0	10.0	40.0		
791	Centrifugal Collector + Wet Scrubber (General)	NEW							55.0	> 99.0	55.0	> 99.0		
792	Centrifugal Collector + Tray-Type Scrubber	NEW							55.0	99.9	55.0	99.9		
793	Centrifugal Collector + Spray Chamber	NEW							70.0	99.9	70.0	99.9		
794	Centrifugal Collector + Mechanically-Aided Scrubber	NEW							70.0	99.9	70.0	99.9		
795	Centrifugal Collector + Packed-Bed Scrubber	NEW							85.0	> 99.9	85.0	> 99.9		
796	Centrifugal Collector + Venturi or Orifice Scrubber	NEW							90.0	> 99.9	90.0	> 99.9		
797	Centrifugal Collector + Condensation Scrubber	NEW							90.0	> 99.9	90.0	> 99.9		
798	Centrifugal Collector + Charged Scrubber	NEW							90.0	> 99.9	90.0	> 99.9		
799	Centrifugal Collector + Electrostatic Precipitator (Dry)	NEW							85.0	99.5	85.0	99.5		
800	Centrifugal Collector + Electrostatic Precipitator (Wet)	NEW	50.0	70.0	50.0	70.0	50.0	70.0	75.0	99.5	75.0	99.5		
801	Centrifugal Collector + Fabric Filter	NEW							85.0	> 99.9	85.0	> 99.9		
802	Centrifugal Collector + Gravel Bed Filter	NEW							85.0	99.0	85.0	99.0		
803	2 Single Cyclones (Conventional)	NEW							30.0	90.0	30.0	90.0		
804	Single Cyclone (Conventional) + Single Cyclone (High Efficiency)	NEW							60.0	95.0	60.0	95.0		

Appendix A: Control Technology Code Numbers and Normal Control Efficiency Range

			PM			PM10			PM2.5			SOx			NOx			CO		
CTC	CONTROL DEVICE/METHOD	OLD CEC	Low		High	Low		High	Low		High	Low		High	Low		High	Low		High
805	Single Cyclone (Conventional) + Single Cyclone (High Throughput)	NEW	80.0		99.0	30.0		90.0	0.0		40.0									
806	Single Cyclone (Conventional) + Wet Scrubber (General)	NEW	70.0	>	99.9	55.0	>	99.0	25.0		97.0									
807	Single Cyclone (Conventional) + Tray-Type Scrubber	NEW	70.0		99.9	55.0		99.9	25.0		97.0									
808	Single Cyclone (Conventional) + Spray Chamber	NEW	70.0		99.9	70.0		99.9	25.0		97.0									
809	Single Cyclone (Conventional) + Mechanically-Aided Scrubber	NEW	70.0		99.9	70.0		99.9	25.0		97.0									
810	Single Cyclone (Conventional) + Packed-Bed Scrubber	NEW	85.0	>	99.9	85.0	>	99.9	25.0		97.0									
811	Single Cyclone (Conventional) + Venturi or Orifice Scrubber	NEW	90.0	>	99.9	90.0	>	99.9	25.0	>	99.0									
812	Single Cyclone (Conventional) + Condensation Scrubber	NEW	90.0	>	99.9	90.0	>	99.9	25.0	>	99.0									
813	Single Cyclone (Conventional) + Charged Scrubber	NEW	90.0	>	99.9	90.0	>	99.9	25.0	>	99.0									
814	Single Cyclone (Conventional) + Electrostatic Precipitator (Dry)	NEW	90.0	>	99.9	85.0		99.5	80.0	>	99.0									
815	Single Cyclone (Conventional) + Electrostatic Precipitator (Wet)	NEW	80.0	>	99.9	75.0		99.5	70.0	>	99.0									
816	Single Cyclone (Conventional) + Fabric Filter	NEW	90.0	>	99.9	85.0	>	99.9	80.0		99.9									
817	Single Cyclone (Conventional) + Gravel Bed Filter	NEW	90.0	>	99.5	85.0		99.0	80.0		99.0									
818	2 Single Cyclones (High Efficiency)	NEW	80.0		99.0	60.0		95.0	20.0		70.0									
819	Single Cyclone (High Efficiency) + Wet Scrubber (General)	NEW	80.0	>	99.9	60.0	>	99.0	25.0		97.0									
820	Single Cyclone (High Efficiency) + Tray-Type Scrubber	NEW	80.0		99.9	60.0		99.9	25.0		97.0									
821	Single Cyclone (High Efficiency) + Spray Chamber	NEW	80.0		99.9	70.0		99.9	25.0		97.0									
822	Single Cyclone (High Efficiency) + Mechanically-Aided Scrubber	NEW	80.0		99.9	70.0		99.9	25.0		97.0									

Appendix A: Control Technology Code Numbers and Normal Control Efficiency Range

CTC	CONTROL DEVICE/METHOD	OLD CEC	TOG Low	TOG High	ROG Low	ROG High	VOT Low	VOT High	POT Low	POT High	PIT Low	PIT High	GIT Low	GIT High
805	Single Cyclone (Conventional) + Single Cyclone (High Throughput)	NEW							30.0	90.0	30.0	90.0		
806	Single Cyclone (Conventional) + Wet Scrubber (General)	NEW							55.0	> 99.0	55.0	> 99.0		
807	Single Cyclone (Conventional) + Tray-Type Scrubber	NEW							55.0	99.9	55.0	99.9		
808	Single Cyclone (Conventional) + Spray Chamber	NEW							70.0	99.9	70.0	99.9		
809	Single Cyclone (Conventional) + Mechanically-Aided Scrubber	NEW							70.0	99.9	70.0	99.9		
810	Single Cyclone (Conventional) + Packed-Bed Scrubber	NEW							85.0	> 99.9	85.0	> 99.9		
811	Single Cyclone (Conventional) + Venturi or Orifice Scrubber	NEW							90.0	> 99.9	90.0	> 99.9		
812	Single Cyclone (Conventional) + Condensation Scrubber	NEW							90.0	> 99.9	90.0	> 99.9		
813	Single Cyclone (Conventional) + Charged Scrubber	NEW							90.0	> 99.9	90.0	> 99.9		
814	Single Cyclone (Conventional) + Electrostatic Precipitator (Dry)	NEW							85.0	99.5	85.0	99.5		
815	Single Cyclone (Conventional) + Electrostatic Precipitator (Wet)	NEW	50.0	70.0	50.0	70.0	50.0	70.0	75.0	99.5	75.0	99.5		
816	Single Cyclone (Conventional) + Fabric Filter	NEW							85.0	> 99.9	85.0	> 99.9		
817	Single Cyclone (Conventional) + Gravel Bed Filter	NEW							85.0	99.0	85.0	99.0		
818	2 Single Cyclones (High Efficiency)	NEW							60.0	95.0	60.0	95.0		
819	Single Cyclone (High Efficiency) + Wet Scrubber (General)	NEW							60.0	> 99.0	60.0	> 99.0		
820	Single Cyclone (High Efficiency) + Tray-Type Scrubber	NEW							60.0	99.9	60.0	99.9		
821	Single Cyclone (High Efficiency) + Spray Chamber	NEW							70.0	99.9	70.0	99.9		
822	Single Cyclone (High Efficiency) + Mechanically-Aided Scrubber	NEW							70.0	99.9	70.0	99.9		

Appendix A: Control Technology Code Numbers and Normal Control Efficiency Range

			PM			PM10			PM2.5			SOx			NOx			CO		
CTC	CONTROL DEVICE/METHOD	OLD CEC	Low		High	Low		High	Low		High	Low		High	Low		High	Low		High
823	Single Cyclone (High Efficiency) + Packed-Bed Scrubber	NEW	85.0	>	99.9	85.0	>	99.9	25.0		97.0									
824	Single Cyclone (High Efficiency) + Venturi or Orifice Scrubber	NEW	90.0	>	99.9	90.0	>	99.9	25.0	>	99.0									
825	Single Cyclone (High Efficiency) + Condensation Scrubber	NEW	90.0	>	99.9	90.0	>	99.9	25.0	>	99.0									
826	Single Cyclone (High Efficiency) + Charged Scrubber	NEW	90.0	>	99.9	90.0	>	99.9	25.0	>	99.0									
827	Single Cyclone (High Efficiency) + Electrostatic Precipitator (Dry)	NEW	90.0	>	99.9	85.0		99.5	80.0	>	99.0									
828	Single Cyclone (High Efficiency) + Electrostatic Precipitator (Wet)	NEW	80.0	>	99.9	75.0		99.5	70.0	>	99.0									
829	Single Cyclone (High Efficiency) + Fabric Filter	NEW	90.0	>	99.9	85.0	>	99.9	80.0		99.9									
830	Single Cyclone (High Efficiency) + Gravel Bed Filter	NEW	90.0		99.9	85.0		99.0	80.0		99.0									
831	2 Single Cyclones (High Throughput)	NEW	80.0		99.0	10.0		40.0	0.0		10.0									
832	Single Cyclone (High Throughput) + Single Cyclone (High Efficiency)	NEW	80.0		99.0	60.0		95.0	20.0		70.0									
833	Single Cyclone (High Throughput) + Wet Scrubber (General)	NEW	80.0	>	99.9	55.0	>	99.0	25.0		97.0									
834	Single Cyclone (High Throughput) + Tray-Type Scrubber	NEW	80.0		99.9	55.0		99.9	25.0		97.0									
835	Single Cyclone (High Throughput) + Spray Chamber	NEW	80.0		99.9	70.0		99.9	25.0		97.0									
836	Single Cyclone (High Throughput) + Mechanically-Aided Scrubber	NEW	80.0		99.9	70.0		99.9	25.0		97.0									
837	Single Cyclone (High Throughput) + Packed-Bed Scrubber	NEW	85.0	>	99.9	85.0	>	99.9	25.0		97.0									
838	Single Cyclone (High Throughput) + Venturi or Orifice Scrubber	NEW	90.0	>	99.9	90.0	>	99.9	25.0	>	99.0									
839	Single Cyclone (High Throughput) + Condensation Scrubber	NEW	90.0	>	99.9	90.0	>	99.9	25.0	>	99.0									
840	Single Cyclone (High Throughput) + Charged Scrubber	NEW	90.0	>	99.9	90.0	>	99.9	25.0	>	99.0									

Appendix A: Control Technology Code Numbers and Normal Control Efficiency Range

			TOG		ROG		VOT		POT		PIT		GIT	
CTC	CONTROL DEVICE/METHOD	OLD CEC	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
823	Single Cyclone (High Efficiency) + Packed-Bed Scrubber	NEW							85.0	> 99.9	85.0	> 99.9		
824	Single Cyclone (High Efficiency) + Venturi or Orifice Scrubber	NEW							90.0	> 99.9	90.0	> 99.9		
825	Single Cyclone (High Efficiency) + Condensation Scrubber	NEW							90.0	> 99.9	90.0	> 99.9		
826	Single Cyclone (High Efficiency) + Charged Scrubber	NEW							90.0	> 99.9	90.0	> 99.9		
827	Single Cyclone (High Efficiency) + Electrostatic Precipitator (Dry)	NEW							85.0	99.5	85.0	99.5		
828	Single Cyclone (High Efficiency) + Electrostatic Precipitator (Wet)	NEW	50.0	70.0	50.0	70.0	50.0	70.0	75.0	99.5	75.0	99.5		
829	Single Cyclone (High Efficiency) + Fabric Filter	NEW							85.0	> 99.9	85.0	> 99.9		
830	Single Cyclone (High Efficiency) + Gravel Bed Filter	NEW							85.0	99.0	85.0	99.0		
831	2 Single Cyclones (High Throughput)	NEW							10.0	40.0	10.0	40.0		
832	Single Cyclone (High Throughput) + Single Cyclone (High Efficiency)	NEW							60.0	95.0	60.0	95.0		
833	Single Cyclone (High Throughput) + Wet Scrubber (General)	NEW							55.0	> 99.0	55.0	> 99.0		
834	Single Cyclone (High Throughput) + Tray-Type Scrubber	NEW							55.0	99.9	55.0	99.9		
835	Single Cyclone (High Throughput) + Spray Chamber	NEW							70.0	99.9	70.0	99.9		
836	Single Cyclone (High Throughput) + Mechanically-Aided Scrubber	NEW							70.0	99.9	70.0	99.9		
837	Single Cyclone (High Throughput) + Packed-Bed Scrubber	NEW							85.0	> 99.9	85.0	> 99.9		
838	Single Cyclone (High Throughput) + Venturi or Orifice Scrubber	NEW							90.0	> 99.9	90.0	> 99.9		
839	Single Cyclone (High Throughput) + Condensation Scrubber	NEW							90.0	> 99.9	90.0	> 99.9		
840	Single Cyclone (High Throughput) + Charged Scrubber	NEW							90.0	> 99.9	90.0	> 99.9		

Appendix A: Control Technology Code Numbers and Normal Control Efficiency Range

			PM			PM10			PM2.5			SOx		NOx		CO	
CTC	CONTROL DEVICE/METHOD	OLD CEC	Low		High	Low		High	Low		High	Low	High	Low	High	Low	High
841	Single Cyclone (High Throughput) + Electrostatic Precipitator (Dry)	NEW	90.0	>	99.9	85.0		99.5	80.0	>	99.0						
842	Single Cyclone (High Throughput) + Electrostatic Precipitator (Wet)	NEW	80.0	>	99.9	75.0		99.5	70.0	>	99.0						
843	Single Cyclone (High Throughput) + Fabric Filter	NEW	90.0	>	99.9	85.0	>	99.9	80.0		99.9						
844	Single Cyclone (High Throughput) + Gravel Bed Filter	NEW	90.0		99.9	85.0		99.0	80.0		99.0						
845	2 Multiple Cyclones with Fly Ash Reinjection	NEW	70.0		99.0	35.0		85.0	20.0		60.0						
846	Multiple Cyclone with Fly Ash Reinjection + Wet Scrubber (General)	NEW	70.0	>	99.9	55.0	>	99.0	25.0		97.0						
847	Multiple Cyclone with Fly Ash Reinjection + Tray-Type Scrubber	NEW	70.0		99.9	55.0		99.9	25.0		97.0						
848	Multiple Cyclone with Fly Ash Reinjection + Spray Chamber	NEW	70.0		99.9	70.0		99.9	25.0		97.0						
849	Multiple Cyclone with Fly Ash Reinjection + Mechanically-Aided Scrubber	NEW	70.0		99.9	70.0		99.9	25.0		97.0						
850	Multiple Cyclone with Fly Ash Reinjection + Packed-Bed Scrubber	NEW	85.0	>	99.9	85.0	>	99.9	25.0		97.0						
851	Multiple Cyclone with Fly Ash Reinjection + Venturi or Orifice	NEW	90.0	>	99.9	90.0	>	99.9	25.0	>	99.0						
852	Multiple Cyclone with Fly Ash Reinjection + Condensation Scrubber	NEW	90.0	>	99.9	90.0	>	99.9	25.0	>	99.0						
853	Multiple Cyclone with Fly Ash Reinjection + Charged Scrubber	NEW	90.0	>	99.9	90.0	>	99.9	25.0	>	99.0						
854	Multiple Cyclone with Fly Ash Reinjection + Electrostatic Precipitator (Dry)	NEW	90.0	>	99.9	85.0		99.5	80.0		99.3						
855	Multiple Cyclone with Fly Ash Reinjection + Electrostatic Precipitator	NEW	80.0	>	99.9	75.0		99.5	70.0		99.3						
856	Multiple Cyclone with Fly Ash Reinjection + Fabric Filter	NEW	90.0	>	99.9	85.0	>	99.9	80.0		99.9						
857	Multiple Cyclone with Fly Ash Reinjection + Gravel Bed Filter	NEW	90.0		99.9	85.0		99.0	80.0		99.0						

Appendix A: Control Technology Code Numbers and Normal Control Efficiency Range

CTC	CONTROL DEVICE/METHOD	OLD CEC	TOG Low	TOG High	ROG Low	ROG High	VOT Low	VOT High	POT Low	POT High	PIT Low	PIT High	GIT Low	GIT High
841	Single Cyclone (High Throughput) + Electrostatic Precipitator (Dry)	NEW							85.0	99.5	85.0	99.5		
842	Single Cyclone (High Throughput) + Electrostatic Precipitator (Wet)	NEW	50.0	70.0	50.0	70.0	50.0	70.0	75.0	99.5	75.0	99.5		
843	Single Cyclone (High Throughput) + Fabric Filter	NEW							85.0	> 99.9	85.0	> 99.9		
844	Single Cyclone (High Throughput) + Gravel Bed Filter	NEW							85.0	99.0	85.0	99.0		
845	2 Multiple Cyclones with Fly Ash Reinjection	NEW							35.0	85.0	35.0	85.0		
846	Multiple Cyclone with Fly Ash Reinjection + Wet Scrubber (General)	NEW							55.0	> 99.0	55.0	> 99.0		
847	Multiple Cyclone with Fly Ash Reinjection + Tray-Type Scrubber	NEW							55.0	99.9	55.0	99.9		
848	Multiple Cyclone with Fly Ash Reinjection + Spray Chamber	NEW							70.0	99.9	70.0	99.9		
849	Multiple Cyclone with Fly Ash Reinjection + Mechanically-Aided Scrubber	NEW							70.0	99.9	70.0	99.9		
850	Multiple Cyclone with Fly Ash Reinjection + Packed-Bed Scrubber	NEW							85.0	> 99.9	85.0	> 99.9		
851	Multiple Cyclone with Fly Ash Reinjection + Venturi or Orifice	NEW							90.0	> 99.9	90.0	> 99.9		
852	Multiple Cyclone with Fly Ash Reinjection + Condensation Scrubber	NEW							90.0	> 99.9	90.0	> 99.9		
853	Multiple Cyclone with Fly Ash Reinjection + Charged Scrubber	NEW							90.0	> 99.9	90.0	> 99.9		
854	Multiple Cyclone with Fly Ash Reinjection + Electrostatic Precipitator (Dry)	NEW							85.0	99.5	85.0	99.5		
855	Multiple Cyclone with Fly Ash Reinjection + Electrostatic Precipitator	NEW	50.0	70.0	50.0	70.0	50.0	70.0	75.0	99.5	75.0	99.5		
856	Multiple Cyclone with Fly Ash Reinjection + Fabric Filter	NEW							85.0	> 99.9	85.0	> 99.9		
857	Multiple Cyclone with Fly Ash Reinjection + Gravel Bed Filter	NEW							85.0	99.0	85.0	99.0		

Appendix A: Control Technology Code Numbers and Normal Control Efficiency Range

			PM			PM10			PM2.5			SOx			NOx			CO		
CTC	CONTROL DEVICE/METHOD	OLD CEC	Low		High	Low		High	Low		High	Low		High	Low		High	Low		High
858	2 Multiple Cyclones without Fly Ash Reinjection	NEW	80.0		99.0	50.0		95.0	20.0		70.0									
859	Multiple Cyclone without Fly Ash Reinjection + Wet Scrubber (General)	NEW	80.0	>	99.9	55.0	>	99.0	25.0		97.0									
860	Multiple Cyclone without Fly Ash Reinjection + Tray-Type Scrubber	NEW	80.0		99.9	55.0		99.9	25.0		97.0									
861	Multiple Cyclone without Fly Ash Reinjection + Spray Chamber	NEW	80.0		99.9	70.0		99.9	25.0		97.0									
862	Multiple Cyclone without Fly Ash Reinjection + Mechanically-Aided Scrubber	NEW	80.0		99.9	70.0		99.9	25.0		97.0									
863	Multiple Cyclone without Fly Ash Reinjection + Packed-Bed Scrubber	NEW	85.0	>	99.9	85.0	>	99.9	25.0		97.0									
864	Multiple Cyclone without Fly Ash Reinjection + Venturi or Orifice	NEW	90.0	>	99.9	90.0	>	99.9	25.0	>	99.0									
865	Multiple Cyclone without Fly Ash Reinjection + Condensation Scrubber	NEW	90.0	>	99.9	90.0	>	99.9	25.0	>	99.0									
866	Multiple Cyclone without Fly Ash Reinjection + Charged Scrubber	NEW	90.0	>	99.9	90.0	>	99.9	25.0	>	99.0									
867	Multiple Cyclone without Fly Ash Reinjection + Electrostatic Precipitator (Dry)	NEW	90.0	>	99.9	85.0		99.5	80.0	>	99.0									
868	Multiple Cyclone without Fly Ash Reinjection + Electrostatic Precipitator (Wet)	NEW	80.0	>	99.9	75.0		99.5	70.0	>	99.0									
869	Multiple Cyclone without Fly Ash Reinjection + Fabric Filter	NEW	90.0	>	99.9	85.0	>	99.9	80.0		99.9									
870	Multiple Cyclone without Fly Ash Reinjection + Gravel Bed Filter	NEW	90.0		99.9	85.0		99.0	80.0		99.0									
871	2 Electrostatic Precipitators (Dry)	NEW	95.0	>	99.9	95.0	>	99.9	90.0	>	99.9									
872	Electrostatic Precipitator (Dry) + Fabric Filter	NEW	95.0	>	99.9	95.0	>	99.9	90.0	>	99.9									
873	Electrostatic Precipitator (Dry) + Wet Scrubber (General)	NEW	90.0	>	99.9	90.0	>	99.9	80.0	>	99.9									
874	Electrostatic Precipitator (Dry) + Tray-Type Scrubber	NEW	90.0	>	99.9	90.0	>	99.9	80.0	>	99.0									

Appendix A: Control Technology Code Numbers and Normal Control Efficiency Range

CTC	CONTROL DEVICE/METHOD	OLD CEC	TOG Low	TOG High	ROG Low	ROG High	VOT Low	VOT High	POT Low	POT High	PIT Low	PIT High	GIT Low	GIT High
858	2 Multiple Cyclones without Fly Ash Reinjection	NEW							50.0	95.0	50.0	95.0		
859	Multiple Cyclone without Fly Ash Reinjection + Wet Scrubber (General)	NEW							55.0	> 99.0	55.0	> 99.0		
860	Multiple Cyclone without Fly Ash Reinjection + Tray-Type Scrubber	NEW							55.0	99.9	55.0	99.9		
861	Multiple Cyclone without Fly Ash Reinjection + Spray Chamber	NEW							70.0	99.9	70.0	99.9		
862	Multiple Cyclone without Fly Ash Reinjection + Mechanically-Aided Scrubber	NEW							70.0	99.9	70.0	99.9		
863	Multiple Cyclone without Fly Ash Reinjection + Packed-Bed Scrubber	NEW							85.0	> 99.9	85.0	> 99.9		
864	Multiple Cyclone without Fly Ash Reinjection + Venturi or Orifice	NEW							90.0	> 99.9	90.0	> 99.9		
865	Multiple Cyclone without Fly Ash Reinjection + Condensation Scrubber	NEW							90.0	> 99.9	90.0	> 99.9		
866	Multiple Cyclone without Fly Ash Reinjection + Charged Scrubber	NEW							90.0	> 99.9	90.0	> 99.9		
867	Multiple Cyclone without Fly Ash Reinjection + Electrostatic Precipitator (Dry)	NEW							85.0	99.5	85.0	99.5		
868	Multiple Cyclone without Fly Ash Reinjection + Electrostatic Precipitator (Wet)	NEW	50.0	70.0	50.0	70.0	50.0	70.0	75.0	99.5	75.0	99.5		
869	Multiple Cyclone without Fly Ash Reinjection + Fabric Filter	NEW							85.0	> 99.9	85.0	> 99.9		
870	Multiple Cyclone without Fly Ash Reinjection + Gravel Bed Filter	NEW							85.0	99.0	85.0	99.0		
871	2 Electrostatic Precipitators (Dry)	NEW							95.0	> 99.9	95.0	> 99.9		
872	Electrostatic Precipitator (Dry) + Fabric Filter	NEW							95.0	> 99.9	95.0	> 99.9		
873	Electrostatic Precipitator (Dry) + Wet Scrubber (General)	NEW							90.0	> 99.9	90.0	> 99.9		
874	Electrostatic Precipitator (Dry) + Tray-Type Scrubber	NEW							90.0	> 99.9	90.0	> 99.9		

Appendix A: Control Technology Code Numbers and Normal Control Efficiency Range

			PM			PM10			PM2.5			SOx		NOx		CO	
CTC	CONTROL DEVICE/METHOD	OLD CEC	Low		High	Low		High	Low		High	Low	High	Low	High	Low	High
875	Electrostatic Precipitator (Dry) + Spray Chamber	NEW	90.0	>	99.9	90.0	>	99.9	80.0	>	99.0						
876	Electrostatic Precipitator (Dry) + Mechanically Aided Scrubber	NEW	90.0	>	99.9	90.0	>	99.9	80.0	>	99.0						
877	Electrostatic Precipitator (Dry) + Packed Bed Scrubber	NEW	90.0	>	99.9	90.0	>	99.9	80.0	>	99.0						
878	Electrostatic Precipitator (Dry) + Venturi or Orifice Scrubber	NEW	95.0	>	99.9	95.0	>	99.9	90.0	>	99.9						
879	Electrostatic Precipitator (Dry) + Condensation Scrubber	NEW	95.0	>	99.9	95.0	>	99.9	90.0	>	99.9						
880	Electrostatic Precipitator (Dry) + Charged Scrubber	NEW	95.0	>	99.9	95.0	>	99.9	90.0	>	99.9						
881	2 Fabric Filters	NEW	95.0	>	99.9	95.0	>	99.9	90.0	>	99.9						
882	Fabric Filter + Wet Scrubber (General)	NEW	90.0	>	99.9	90.0	>	99.9	80.0	>	99.9						
883	Fabric Filter + Tray-Type Scrubber	NEW	90.0	>	99.9	90.0	>	99.9	80.0		99.9						
884	Fabric Filter + Spray Chamber	NEW	90.0	>	99.9	90.0	>	99.9	80.0		99.9						
885	Fabric Filter + Mechanically Aided Scrubber	NEW	90.0	>	99.9	90.0	>	99.9	80.0		99.9						
886	Fabric Filter + Packed Bed Scrubber	NEW	90.0	>	99.9	90.0	>	99.9	80.0		99.9						
887	Fabric Filter + Venturi or Orifice Scrubber	NEW	95.0	>	99.9	95.0	>	99.9	90.0	>	99.9						
888	Fabric Filter + Condensation Scrubber	NEW	95.0	>	99.9	95.0	>	99.9	90.0	>	99.9						
889	Fabric Filter + Charged Scrubber	NEW	95.0	>	99.9	95.0	>	99.9	90.0	>	99.9						
890	Fabric Filter + Electrostatic Precipitator (Wet)	NEW	95.0	>	99.9	95.0	>	99.9	90.0	>	99.9						
891	Gravel Bed Filter + Fabric Filter	NEW	90.0	>	99.9	90.0	>	99.9	80.0		99.9						
892	2 Wet Scrubbers (General, Not Classified)	NEW	70.0	>	99.9	70.0	>	99.9	25.0	>	99.0						

Appendix A: Control Technology Code Numbers and Normal Control Efficiency Range

			TOG		ROG		VOT		POT		PIT		GIT	
CTC	CONTROL DEVICE/METHOD	OLD CEC	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
875	Electrostatic Precipitator (Dry) + Spray Chamber	NEW							90.0	> 99.9	90.0	> 99.9		
876	Electrostatic Precipitator (Dry) + Mechanically Aided Scrubber	NEW							90.0	> 99.9	90.0	> 99.9		
877	Electrostatic Precipitator (Dry) + Packed Bed Scrubber	NEW							90.0	> 99.9	90.0	> 99.9		
878	Electrostatic Precipitator (Dry) + Venturi or Orifice Scrubber	NEW							95.0	> 99.9	95.0	> 99.9		
879	Electrostatic Precipitator (Dry) + Condensation Scrubber	NEW							95.0	> 99.9	95.0	> 99.9		
880	Electrostatic Precipitator (Dry) + Charged Scrubber	NEW							95.0	> 99.9	95.0	> 99.9		
881	2 Fabric Filters	NEW							95.0	> 99.9	95.0	> 99.9		
882	Fabric Filter + Wet Scrubber (General)	NEW							90.0	> 99.9	90.0	> 99.9		
883	Fabric Filter + Tray-Type Scrubber	NEW							90.0	> 99.9	90.0	> 99.9		
884	Fabric Filter + Spray Chamber	NEW							90.0	> 99.9	90.0	> 99.9		
885	Fabric Filter + Mechanically Aided Scrubber	NEW							90.0	> 99.9	90.0	> 99.9		
886	Fabric Filter + Packed Bed Scrubber	NEW							90.0	> 99.9	90.0	> 99.9		
887	Fabric Filter + Venturi or Orifice Scrubber	NEW							95.0	> 99.9	95.0	> 99.9		
888	Fabric Filter + Condensation Scrubber	NEW							95.0	> 99.9	95.0	> 99.9		
889	Fabric Filter + Charged Scrubber	NEW							95.0	> 99.9	95.0	> 99.9		
890	Fabric Filter + Electrostatic Precipitator (Wet)	NEW	50.0	70.0	50.0	70.0	50.0	70.0	95.0	> 99.9	95.0	> 99.9		
891	Gravel Bed Filter + Fabric Filter	NEW							90.0	> 99.9	90.0	> 99.9		
892	2 Wet Scrubbers (General, Not Classified)	NEW							70.0	> 99.9	70.0	> 99.9		

Appendix A: Control Technology Code Numbers and Normal Control Efficiency Range

			PM			PM10			PM2.5			SOx		NOx		CO	
CTC	CONTROL DEVICE/METHOD	OLD CEC	Low		High	Low		High	Low		High	Low	High	Low	High	Low	High
893	2 Venturi or Orifice Scrubbers	NEW	90.0	>	99.9	90.0	>	99.9	70.0	>	99.9						
894	2 Tray-Type Scrubbers (Impingement Plate, Perforated Plate, Horizontal Impingement-Plate (Baffle))	NEW	70.0	>	99.0	70.0	>	99.0	25.0		99.0						
895	Tray-Type Scrubber + Spray Chamber	NEW	70.0	>	99.9	70.0	>	99.0	25.0		99.0						
896	Tray-Type Scrubber + Mechanically Aided Scrubber	NEW	70.0	>	99.9	70.0	>	99.0	25.0		99.0						
897	Tray-Type Scrubber + Packed Bed Scrubber	NEW	85.0	>	99.0	85.0	>	99.0	25.0		99.0						
898	Tray-Type Scrubber + Venturi or Orifice Scrubber	NEW	90.0	>	99.9	90.0	>	99.9	25.0	>	99.0						
899	Tray-Type Scrubber + Condensation Scrubber	NEW	90.0	>	99.9	90.0	>	99.9	25.0	>	99.0						
900	Tray-Type Scrubber + Charged Scrubber	NEW	90.0	>	99.9	90.0	>	99.9	25.0	>	99.0						
901	2 Spray Chambers (Spray Tower, Cyclonic Spray Tower, Vane-Type	NEW	80.0	>	99.9	80.0	>	99.9	25.0	>	99.0						
902	Spray Chamber + Mechanically Aided Scrubber	NEW	80.0	>	99.9	80.0	>	99.0	25.0		99.0						
903	Spray Chamber + Packed Bed Scrubber	NEW	85.0	>	99.9	85.0	>	99.0	25.0		99.0						
904	Spray Chamber + Venturi or Orifice Scrubber	NEW	90.0	>	99.9	90.0	>	99.9	25.0	>	99.0						
905	Spray Chamber + Condensation Scrubber	NEW	90.0	>	99.9	90.0	>	99.9	25.0	>	99.0						
906	Spray Chamber + Charged Scrubber	NEW	90.0	>	99.9	90.0	>	99.9	25.0	>	99.0						
907	2 Mechanically-Aided Scrubbers	NEW	80.0	>	99.9	80.0	>	99.9	70.0	>	99.0						
908	Mechanically Aided Scrubber + Packed Bed Scrubber	NEW	85.0	>	99.0	85.0	>	99.0	25.0		99.0						
909	Mechanically Aided Scrubber + Venturi or Orifice Scrubber	NEW	90.0	>	99.9	90.0	>	99.9	25.0	>	99.0						
910	Mechanically Aided Scrubber + Condensation Scrubber	NEW	90.0	>	99.9	90.0	>	99.9	25.0	>	99.0						

Appendix A: Control Technology Code Numbers and Normal Control Efficiency Range

CTC	CONTROL DEVICE/METHOD	OLD CEC	TOG Low	TOG High	ROG Low	ROG High	VOT Low	VOT High	POT Low	POT High	PIT Low	PIT High	GIT Low	GIT High
893	2 Venturi or Orifice Scrubbers	NEW							90.0	> 99.9	90.0	> 99.9		
894	2 Tray-Type Scrubbers (Impingement Plate, Perforated Plate, Horizontal Impingement-Plate (Baffle))	NEW							70.0	> 99.0	70.0	> 99.0		
895	Tray-Type Scrubber + Spray Chamber	NEW							70.0	> 99.0	70.0	> 99.0		
896	Tray-Type Scrubber + Mechanically Aided Scrubber	NEW							70.0	> 99.0	70.0	> 99.0		
897	Tray-Type Scrubber + Packed Bed Scrubber	NEW							85.0	> 99.0	85.0	> 99.0		
898	Tray-Type Scrubber + Venturi or Orifice Scrubber	NEW							90.0	> 99.9	90.0	> 99.9		
899	Tray-Type Scrubber + Condensation Scrubber	NEW							90.0	> 99.9	90.0	> 99.9		
900	Tray-Type Scrubber + Charged Scrubber	NEW							90.0	> 99.9	90.0	> 99.9		
901	2 Spray Chambers (Spray Tower, Cyclonic Spray Tower, Vane-Type	NEW							80.0	> 99.9	80.0	> 99.9		
902	Spray Chamber + Mechanically Aided Scrubber	NEW							80.0	> 99.0	80.0	> 99.0		
903	Spray Chamber + Packed Bed Scrubber	NEW							85.0	> 99.0	85.0	> 99.0		
904	Spray Chamber + Venturi or Orifice Scrubber	NEW							90.0	> 99.9	90.0	> 99.9		
905	Spray Chamber + Condensation Scrubber	NEW							90.0	> 99.9	90.0	> 99.9		
906	Spray Chamber + Charged Scrubber	NEW							90.0	> 99.9	90.0	> 99.9		
907	2 Mechanically-Aided Scrubbers	NEW							80.0	> 99.9	80.0	> 99.9		
908	Mechanically Aided Scrubber + Packed Bed Scrubber	NEW							85.0	> 99.0	85.0	> 99.0		
909	Mechanically Aided Scrubber + Venturi or Orifice Scrubber	NEW							90.0	> 99.9	90.0	> 99.9		
910	Mechanically Aided Scrubber + Condensation Scrubber	NEW							90.0	> 99.9	90.0	> 99.9		

Appendix A: Control Technology Code Numbers and Normal Control Efficiency Range

			PM			PM10			PM2.5			SOx		NOx		CO	
CTC	CONTROL DEVICE/METHOD	OLD CEC	Low		High	Low		High	Low		High	Low	High	Low	High	Low	High
911	Mechanically Aided Scrubber + Charged Scrubber	NEW	90.0	>	99.9	90.0	>	99.9	25.0	>	99.0						
912	2 Packed-Bed Scrubbers (Fiber-Bed, Moving-Bed, Cross-Flow, Grid-Packed)	NEW	85.0	>	99.0	85.0	>	99.0	25.0		99.0						
913	Packed Bed Scrubber + Venturi or Orifice Scrubber	NEW	90.0	>	99.9	90.0	>	99.9	25.0	>	99.0						
914	Packed Bed Scrubber + Condensation Scrubber	NEW	90.0	>	99.9	90.0	>	99.9	25.0	>	99.0						
915	Packed Bed Scrubber + Charged Scrubber	NEW	90.0	>	99.9	90.0	>	99.9	25.0	>	99.0						
916	2 Blade-Type Mist Eliminators	NEW	90.0		99.9	90.0		99.9	60.0		70.0						
917	2 Mesh-Type Mist Eliminators	NEW	95.0	>	99.9	95.0	>	99.9	95.0		99.9						
918	Blade-Type Mist Eliminator + Mesh-Type Mist Eliminator	NEW	95.0	>	99.9	95.0	>	99.9	95.0		99.9						
919	Plastic Balls for Electroplating Tanks + Blade-Type Mist Eliminator	NEW	80.0		98.0	80.0		98.0	50.0		70.0						
920	Plastic Balls for Electroplating Tanks + Mesh-Type Mist Eliminator	NEW	95.0		99.9	95.0		99.9	95.0		99.9						

Appendix A: Control Technology Code Numbers and Normal Control Efficiency Range

CTC	CONTROL DEVICE/METHOD	OLD CEC	TOG Low	TOG High	ROG Low	ROG High	VOT Low	VOT High	POT Low	POT High	PIT Low	PIT High	GIT Low	GIT High
911	Mechanically Aided Scrubber + Charged Scrubber	NEW							90.0	> 99.9	90.0	> 99.9		
912	2 Packed-Bed Scrubbers (Fiber-Bed, Moving-Bed, Cross-Flow, Grid-Packed)	NEW							85.0	> 99.0	85.0	> 99.0		
913	Packed Bed Scrubber + Venturi or Orifice Scrubber	NEW							90.0	> 99.9	90.0	> 99.9		
914	Packed Bed Scrubber + Condensation Scrubber	NEW							90.0	> 99.9	90.0	> 99.9		
915	Packed Bed Scrubber + Charged Scrubber	NEW							90.0	> 99.9	90.0	> 99.9		
916	2 Blade-Type Mist Eliminators	NEW							90.0	99.9	90.0	99.9		
917	2 Mesh-Type Mist Eliminators	NEW							95.0	> 99.9	95.0	> 99.9		
918	Blade-Type Mist Eliminator + Mesh-Type Mist Eliminator	NEW							95.0	> 99.9	95.0	> 99.9		
919	Plastic Balls for Electroplating Tanks + Blade-Type Mist Eliminator	NEW									80.0	98.0		
920	Plastic Balls for Electroplating Tanks + Mesh-Type Mist Eliminator	NEW									95.0	99.9		