United States
Environmental Protection
Agency

Air Pollution Training Institute (APTI)
Environmental Research Center, MD 17
Research Triangle Park, NC 27711

April 2014

Air

Inspection of Gas Control Devices and Selected Industries

Slide Manual

APTI Course 455
Fourth Edition

Authors

Jerry W. Crowder, PhD, PE
Crowder Environmental Associates, Inc.

John R. Richards, PhD, PE
Air Control Techniques, PC

Inspection of Gas Control Devices and Selected Industries

Slide Manual

APTI Course 455
Fourth Edition

Authors

Jerry W. Crowder, Ph.D., P.E.
Crowder Environmental Associates, Inc.
120 Cherry Circle
Dyersburg, Tennessee 38024

John R. Richards, Ph.D., P.E.
Air Control Techniques, P.C.
301 E. Durham
Cary, NC 27513

This page intentionally left blank.

TABLE OF CONTENTS

		Page
Chapter 1	Baseline Inspection Techniques	1-1
Chapter 2	Adsorbers	2-1
Chapter 3	Thermal and Catalytic Oxidizers	3-1
Chapter 4	Condensers	4-1
Chapter 5	Nitrogen Oxides Control Systems	5-1
Chapter 6	Sulfur Oxides Control Systems	6-1
Chapter 7	Utility and Industrial Boilers	7-1
Chapter 8	Municipal and Medical Waste Incinerators	8-1
Chapter 9	Iron and Steel Processes	9-1
Chapter 10	Asphalt Plants	10-1

This page intentionally left blank.

Chapter 1

Baseline Inspection Techniques

Responsibilities of Inspectors

- Compliance evaluation
- Testing and sampling
- Litigation assistance
- Citizen complaint investigation
- Agency representation

Compliance Monitoring Activities

- Inspections
- Evaluations
  - Full compliance evaluations
  - Partial compliance evaluations
- Civil investigations
- Record reviews
- Information requests

Inspections

- Visits to a facility or site to gather information to determine compliance status
- Inspections generally include pre-inspection activities before entering the facility or site
- Inspections are usually conducted on single-media programs

Inspection Activities

- Interviewing facility or site representatives
- Reviewing records and reports
- Taking photographs
- Collecting samples
- Observing facility or site operations

Clean Air Act Evaluations

- Full Compliance Evaluation (FCE)
- Partial Compliance Evaluation (PCE)

Full Compliance Evaluation

- Comprehensive evaluation of compliance status of the facility
- Looks for all regulated pollutants at all regulated emission units
- Addresses the compliance status of each unit
- Addresses facility's continuing ability to maintain compliance at each emission unit.

FCE Activities

- Review all reports and the underlying records
- Assess air pollution control devices and operating conditions
- Assess process parameters
- Observe visible emissions
- Review facility records and operating logs
- Stack test

Partial Compliance Evaluation

- Focused on subset of regulated pollutants, regulatory requirements, or emission units at a given facility
- More comprehensive than a cursory review of individual reports
- May combine several evaluations to satisfy the annual requirements of a FCE

Civil Investigations

- Detailed assessment of compliance status
- Potential for serious, widespread and/or continuing civil or criminal violations
- Requires significant time to complete

Record Reviews

- Review of records to evaluate compliance status
- May or may not be combined with field work

Information Requests

- Enforceable, written request for information to evaluate compliance status
- Potential for serious, widespread and/or continuing civil or criminal violations

Major Elements of Inspection

- File review
- Inspection preparation
- Pre-inspection meeting
- Plant inspection
- Post-inspection meeting
- Inspection report preparation

Inspection Analyses

- Direct comparison with promulgated standards
- Comparison of inspection units with similar units
- Evaluation of shifts from baseline operating conditions

Examples of Direct Comparison Inspections

Regulation	Parameter	Type of Instrument or Analysis Used for Direct Comparison
Municipal Waste Incinerators 40 CFR Part 60, Subpart Ea	Incinerator operating rate	Steam rate gauge
	CO concentration	CO continuous emission monitor
	Control system inlet gas temperature	Thermocouple or equivalent temperature monitor
Fossil Fuel Fired Boilers 40 CFR Part 60, Subparts Da and Db	Sulfur dioxide concentration	Sulfur dioxide continuous emission monitor
	Nitrogen oxides concentration	Nitrogen oxides continuous emission monitor
	Visible emissions	Opacity monitor
Asbestos Removal	Visible emissions	Visible emissions observer
	Adequately wet asbestos-containing material during removal	Observation of work practices

Inspection Analyses

- Direct comparison with promulgated standards
- Comparison of inspection units with similar units
- Evaluation of shifts from baseline operating conditions

Site Specific Factors

- Particle size distrubution
- Adequacy of gas distribution
- Liquid surface tension (scrubbers)
- Droplet size distribution (scrubbers)
- Gas temperature spatial differences
- Gas flow temporal variations
- Particle composition
- Particle resistivity (ESPs)
- Dust cake cohesiveness (ESPs and filters)
- Distribution of cleaning energy (ESPs and filters)
- Mist eliminator efficiency
- Venturi throat damper condition (scrubbers)
- pH (scrubbers)

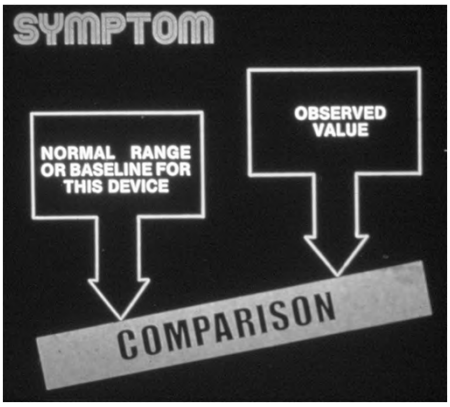
Inspection Analyses

- Direct comparison with promulgated standards
- Comparison of inspection units with similar units
- Evaluation of shifts from baseline operating conditions

Principles of Baseline Analyses

- Principle Number One

  Changes over time are evaluated for individual units



Principles of Baseline Analyses

- Principle Number Two

Sets of data are evaluated, as opposed to relying on a single measurement

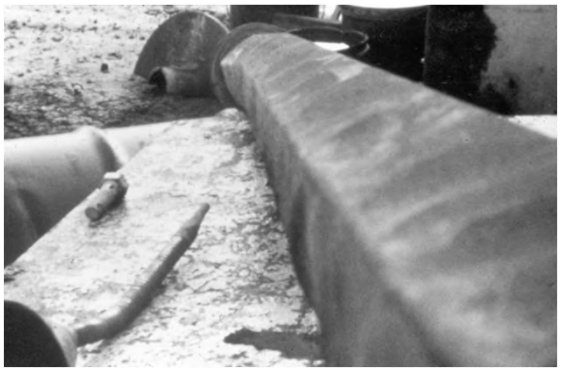
Scrubber Symptoms

- Decreased pressure drop
- Increased plume opacity
- Increased outlet gas temperature
- Decrease liquid flow rate

Principles of Baseline Analyses

- Principle Number Three

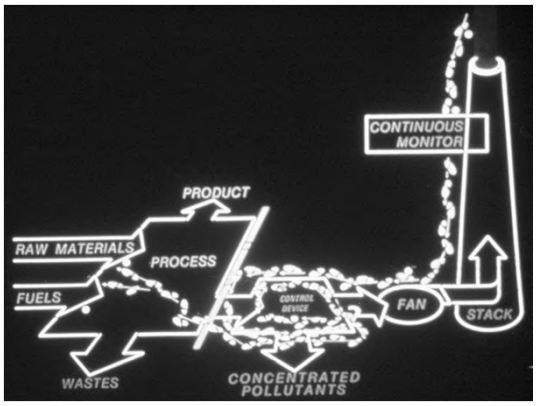
The inspection scope should include component failure information and general observations and should not be limited to operating data alone



Principles of Baseline Analyses

- Principle Number Four

  Inspection data and observations must be organized in a coherent fashion and evaluated during the compliance inspection



Principles of Baseline Analyses

- Principle Number Five

  Inspectors must have the flexibility to exercise professional judgment during the inspection

Principles of Baseline Analyses

- Principle Number Six

  Baseline analyses or other indirect compliance analyses are not generally used as a stand-alone basis for enforcement actions

Practical Limits to Inspections

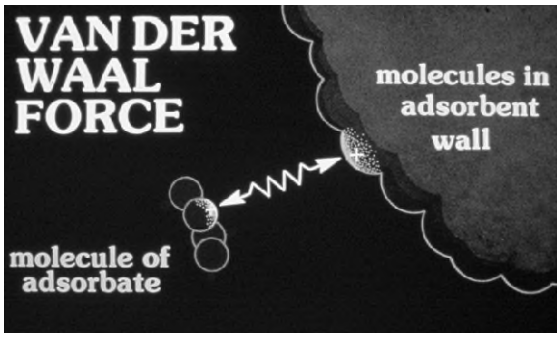
- Time constraints
- Health and safety hazards
- Lack of plant instrumentation

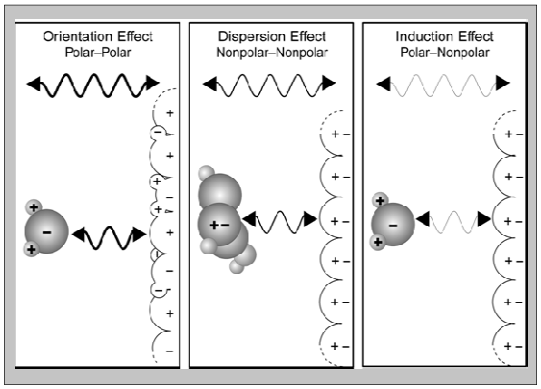
Chapter 2

Adsorbers

Types of Adsorption Processes

- Chemical adsorption
- Physical adsorption

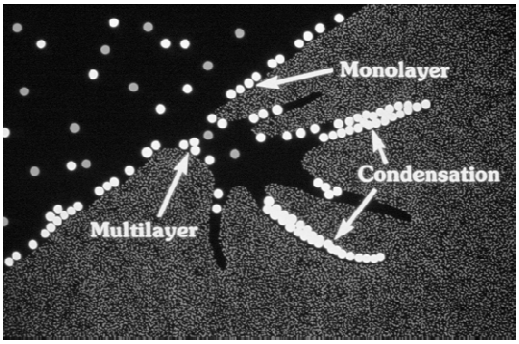




Types of Adsorbents

Polar	Non-Polar
Silica gel	Activated carbon
Activated alumina	Synthetic polymers
Molecular sieves	
Synthetic polymers	

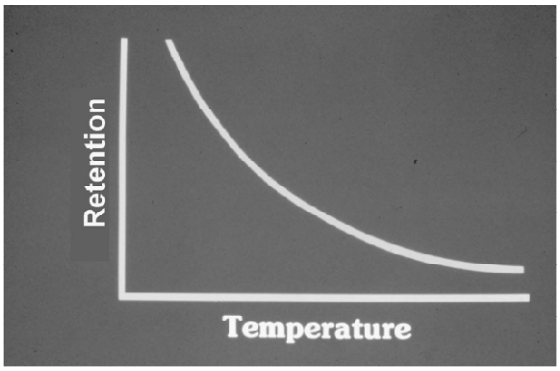
Adsorption Steps

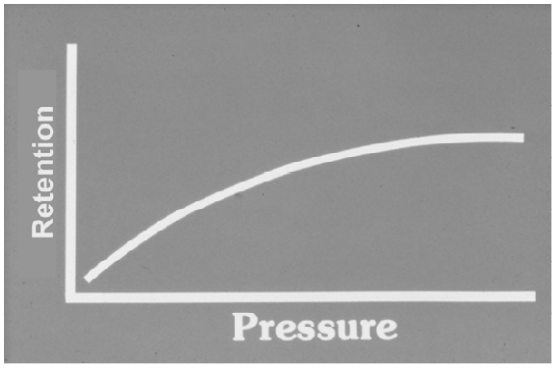


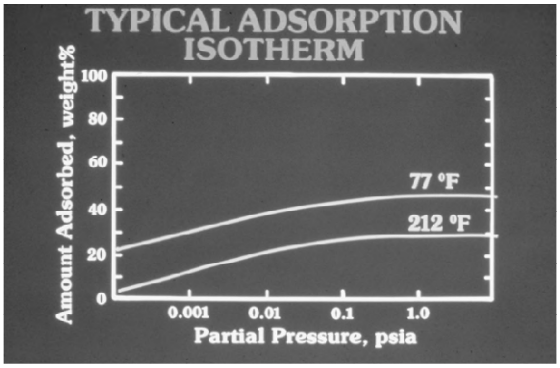
Adsorption Capacity

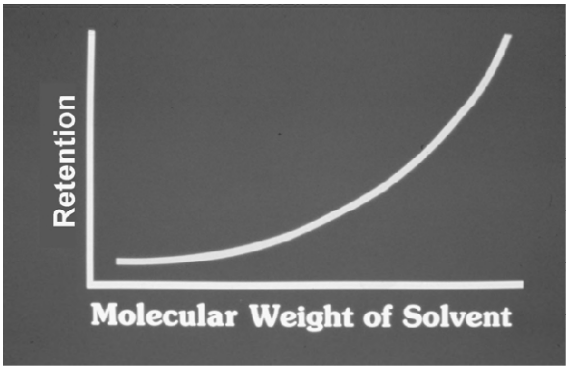
Retention

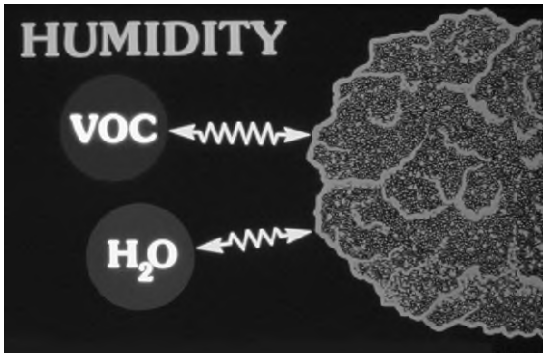
- Lbs of VOC adsorbed per 100 lbs of carbon
- Weight percent

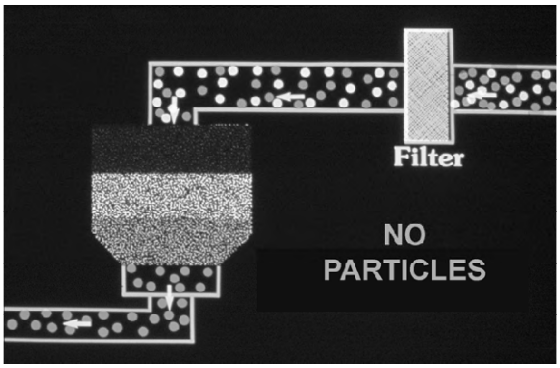




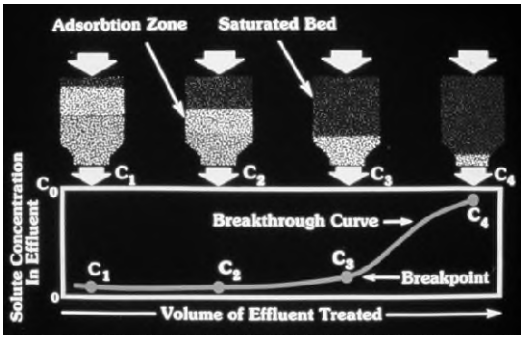

TYPICAL ADSORPTION ISOTHERM
Amount Adsorbed, weight%
100
80
60
40
20
0
77 °F
212 °F
0.001
0.01
0.1
1.0
Partial Pressure, psia


Retention
Molecular Weight of Solvent


HUMIDITY
VOC
H_2O



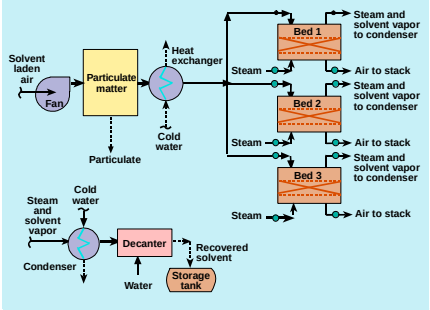
Adsorption Capacity



Regeneration Methods

- Thermal swing
  - Steam
  - Hot gas
- Pressure swing

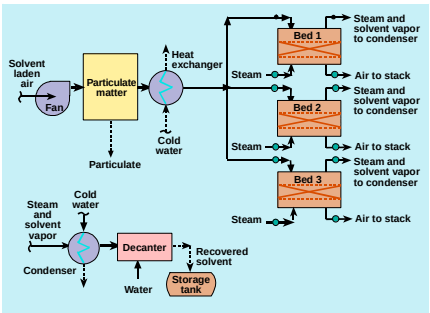
Steam Regeneration



Regeneration Methods

- Thermal swing
  - Steam
  - Hot gas
- Pressure swing

Hot Gas Regeneration



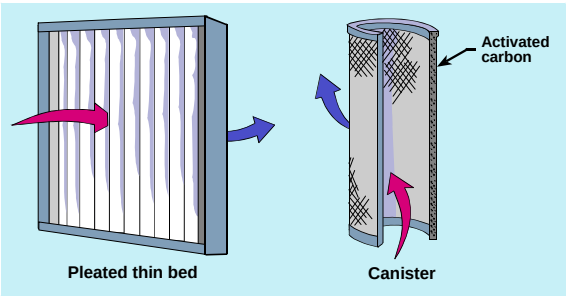
Regeneration Methods

- Thermal swing
  - Steam
  - Hot gas
- Pressure swing

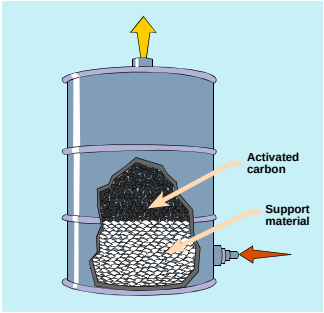
Types of Adsorption Systems

- On-site regeneration
- Off-site regeneration

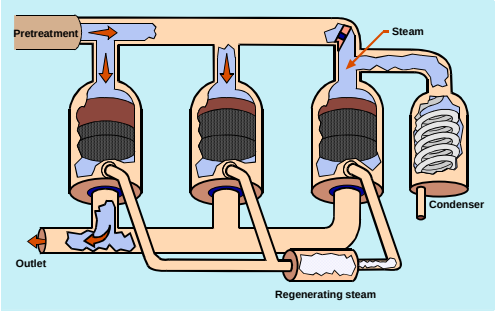
Off-Site Regeneration Adsorbers



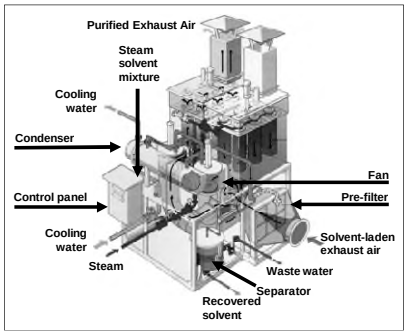
Canister Adsorber

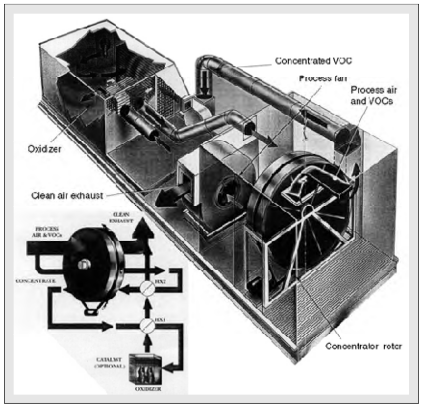


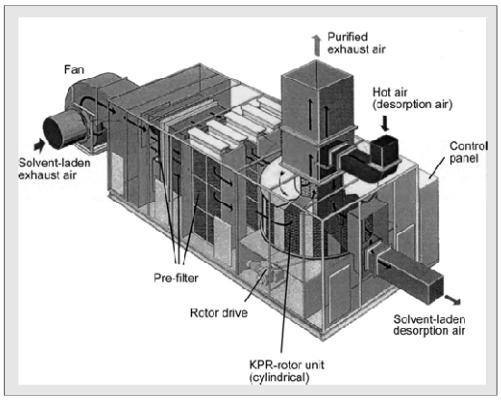
On-Site Regeneration Fixed-Bed System

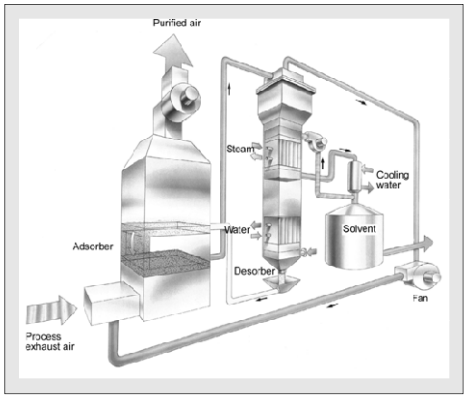


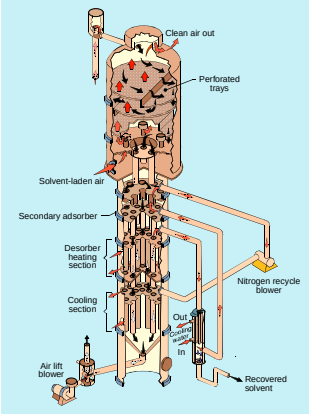
Carbon Fiber Adsorber



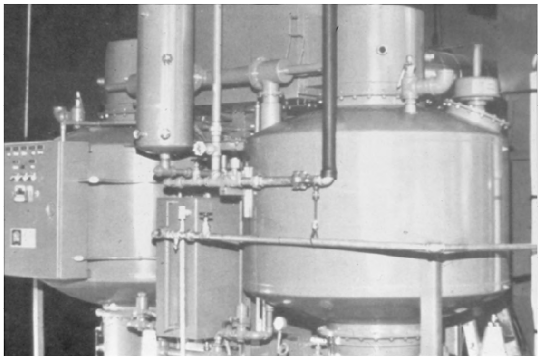

Concentrated VOC
Process air
and VOCs
Oxidizer
Clean air exhaust
Concentrator rotor

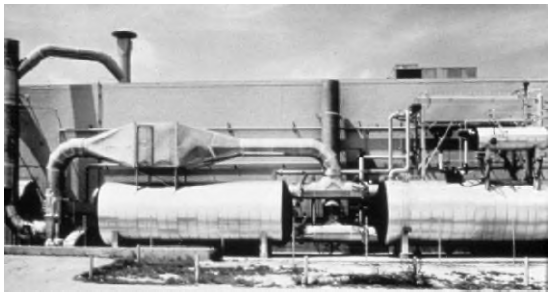

Purified
exhaust air
Fan
Hot air
(desorption air)
Control
panel
Solvent-laden
exhaust air
Pre-filter
Rotor drive
Solvent-laden
desorption air
KPR-rotor unit
(cylindrical)

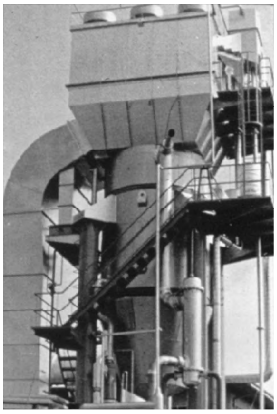

Purified air
Steam
Cooling
water
Water
Solvent
Adsorber
Desorber
Fan
Process
exhaust air



Fluidized Bed Adsorber







Compliance Inspection

General:

- Outlet VOC concentration
- Inlet gas temperature
- Adsorption/desorption cycle times
- Steam pressure and temperature
- Adsorber physical condition

Compliance Inspection

General:

- Outlet VOC concentration
- Inlet gas temperature
- Adsorption/desorption cycle times
- Steam pressure and temperature
- Adsorber physical condition

Compliance Inspection

General:

- Outlet VOC concentration
- Inlet gas temperature
- Adsorption/desorption cycle times
- Steam pressure and temperature
- Adsorber physical condition

Compliance Inspection

General:

- Outlet VOC concentration
- Inlet gas temperature
- Adsorption/desorption cycle times
- Steam pressure and temperature
- Adsorber physical condition

Compliance Inspection

General:

- Outlet VOC concentration
- Inlet gas temperature
- Adsorption/desorption cycle times
- Steam pressure and temperature
- Adsorber physical condition

Compliance Inspection

General:

- Outlet VOC concentration
- Inlet gas temperature
- Adsorption/desorption cycle times
- Steam pressure and temperature
- Adsorber physical condition

Compliance Inspection

Follow-up:

- Inlet concentration (%LEL) and hood static pressure
- Inlet and outlet static pressures
- VOC detector calibration and maintenance
- Solvent recovery rates

Compliance Inspection

Follow-up:

- Inlet concentration (%LEL) and hood static pressure
- Inlet and outlet static pressures
- VOC detector calibration and maintenance
- Solvent recovery rates

Compliance Inspection

Follow-up:

- Inlet concentration (%LEL) and hood static pressure
- Inlet and outlet static pressures
- VOC detector calibration and maintenance
- Solvent recovery rates

Compliance Inspection

Follow-up:

- Inlet concentration (%LEL) and hood static pressure
- Inlet and outlet static pressures
- VOC detector calibration and maintenance
- Solvent recovery rates

Compliance Inspection

Follow-up:

- Inlet concentration (%LEL) and hood static pressure
- Inlet and outlet static pressures
- VOC detector calibration and maintenance
- Solvent recovery rates

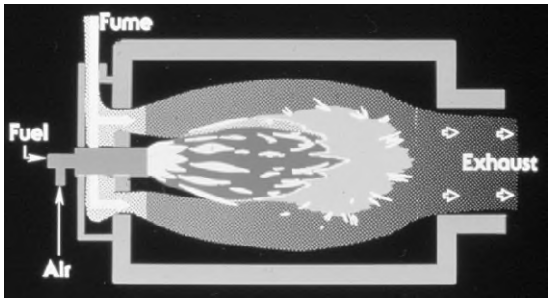
Chapter 3

Thermal and Catalytic Oxidizers

Types of Oxidization Processes

- Flares
- Thermal oxidizers
  - Dedicated units
  - Process heaters and boilers
- Catalytic oxidizers

Thermal Oxidizer



Parameters Affecting Performance

- Temperature
- Residence time
- VOC composition and concentration

Temperature

- >100°F above auto-ignition temperature
- Reaction rate increases with temperature
- >1,300°F to convert CO to CO_2
- Typically 1,300-1,800°F

Residence Time

$$t = \frac{V}{Q}$$

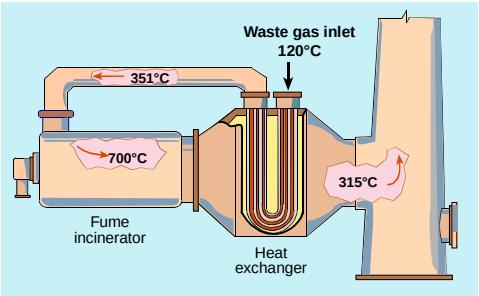
Q = actual volumetric flow rate
V = effective volume

Typically 0.3-2.0 seconds

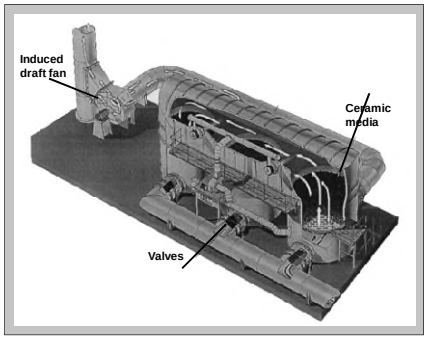
VOC Composition and Concentration

- Composition affects oxidation temperature
- Reaction rate increases with concentration
- Source of energy
  - 100% LEL vapors contain about 50 Btu/scf
  - Oxidizing 1% LEL causes about a 27°F temperature rise in the gas stream

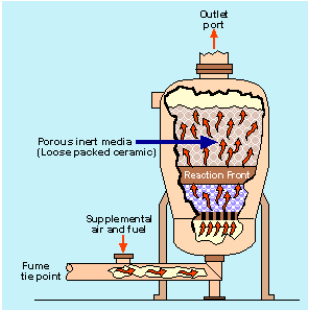
Recuperative Thermal Oxidizer



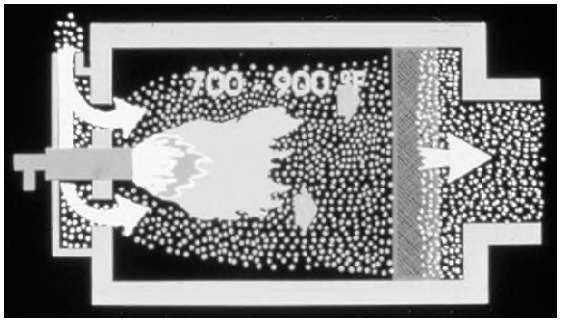
Regenerative Thermal Oxidizer

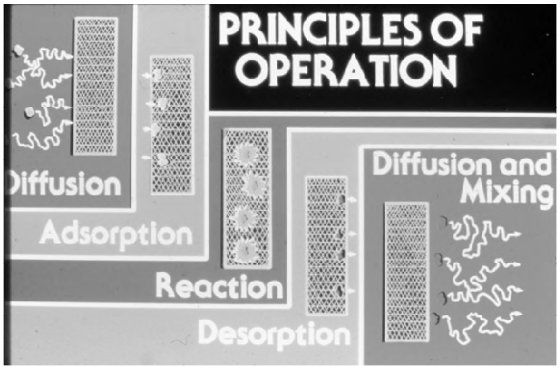


Flameless Thermal Oxidizer



Catalytic Oxidizer



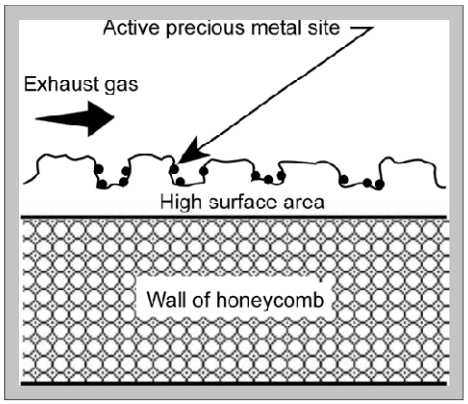


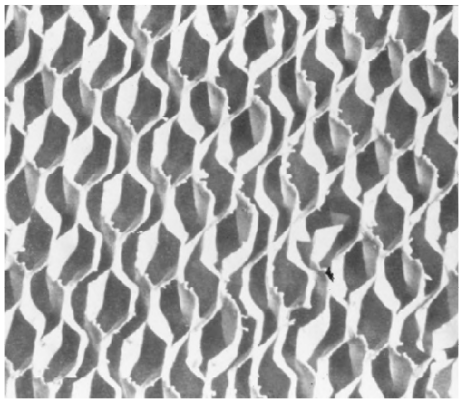
Catalyst Materials

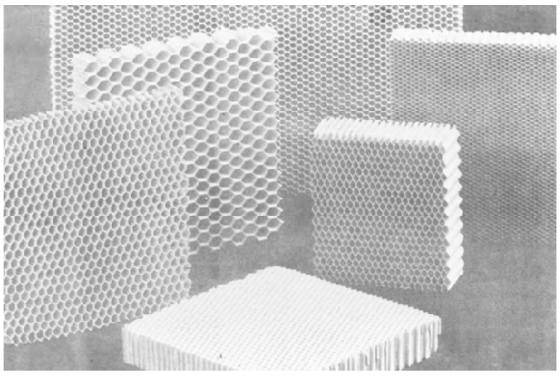
- Noble metal oxides
  - Platinum
  - Palladium
  - Rhodium
- Base metal oxides
  - Manganese
  - Chromium
  - Vanadium

Catalyst Configurations

- Fixed bed
  - Beaded
  - Monolithic
- Fluidized bed







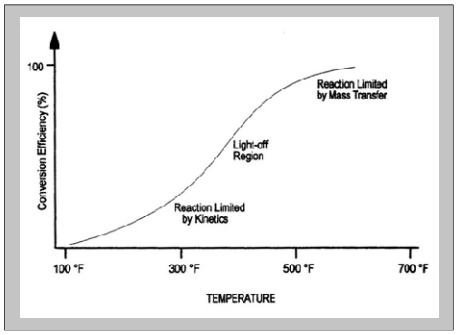
Parameters Affecting Performance

- Temperature
- Space velocity
- VOC composition and concentration
- Presence of poisons or inhibitors

Temperature

- ~100°F above light-off temperature
- Reaction rate increases with temperature
- Typical inlet temperature: 500-600°F
- Typical outlet temperature: 700-900°F
- Maximum outlet temperature: 1,100-1,200°F

Generic Light-Off Curve



Space Velocity

$$SV = \frac{Q_{std}}{BV}$$

Q_{std} = standard volumetric flow rate
BV = catalyst bed volume

Efficiency increases with decreasing space velocity

Typically 30,000-40,000 hr^{-1} for noble metals
10,000-15,000 hr^{-1} for base metals

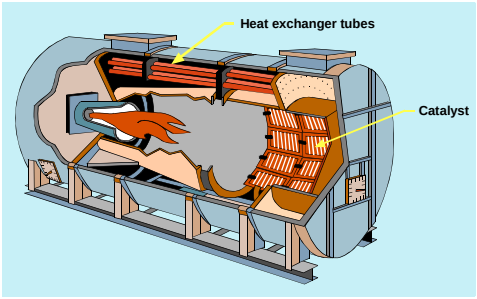
VOC Composition and Concentration

- Composition affects oxidation temperature
- Reaction rate increases with concentration
- Source of energy
  - 100% LEL vapors contain about 50 Btu/scf
  - Oxidizing 1% LEL causes about a 27°F temperature rise in the gas stream

Catalyst Performance Problems

- Fouling
- Poisoning
- Masking
- Thermal aging

Catalytic Oxidizer



Compliance Inspection

General:

- Visible emissions
- Outlet VOC concentration
- Thermal oxidizer outlet temperature
- Catalytic oxidizer inlet and outlet temperature
- Oxidizer physical condition

Compliance Inspection

General:

- Visible emissions
- Outlet VOC concentration
- Thermal oxidizer outlet temperature
- Catalytic oxidizer inlet and outlet temperature
- Oxidizer physical condition

Compliance Inspection

General:

- Visible emissions
- Outlet VOC concentration
- Thermal oxidizer outlet temperature
- Catalytic oxidizer inlet and outlet temperature
- Oxidizer physical condition

Compliance Inspection

General:

- Visible emissions
- Outlet VOC concentration
- Thermal oxidizer outlet temperature
- Catalytic oxidizer inlet and outlet temperature
- Oxidizer physical condition

Compliance Inspection

General:

- Visible emissions
- Outlet VOC concentration
- Thermal oxidizer outlet temperature
- Catalytic oxidizer inlet and outlet temperature
- Oxidizer physical condition

Compliance Inspection

General:

- Visible emissions
- Outlet VOC concentration
- Thermal oxidizer outlet temperature
- Catalytic oxidizer inlet and outlet temperature
- Oxidizer physical condition

Compliance Inspection

Follow-up:

- Inlet concentration (%LEL) and hood static pressure
- Inlet and outlet static pressures
- VOC detector calibration and maintenance
- Internal inspection reports
- Catalyst activity test data

Compliance Inspection

Follow-up:

- Inlet concentration (%LEL) and hood static pressure
- Inlet and outlet static pressures
- VOC detector calibration and maintenance
- Internal inspection reports
- Catalyst activity test data

Compliance Inspection

Follow-up:

- Inlet concentration (%LEL) and hood static pressure
- Inlet and outlet static pressures
- VOC detector calibration and maintenance
- Internal inspection reports
- Catalyst activity test data

Compliance Inspection

Follow-up:

- Inlet concentration (%LEL) and hood static pressure
- Inlet and outlet static pressures
- VOC detector calibration and maintenance
- Internal inspection reports
- Catalyst activity test data

Compliance Inspection

Follow-up:

- Inlet concentration (%LEL) and hood static pressure
- Inlet and outlet static pressures
- VOC detector calibration and maintenance
- Internal inspection reports
- Catalyst activity test data

Compliance Inspection

Follow-up:

- Inlet concentration (%LEL) and hood static pressure
- Inlet and outlet static pressures
- VOC detector calibration and maintenance
- Internal inspection reports
- Catalyst activity test data

Chapter 4

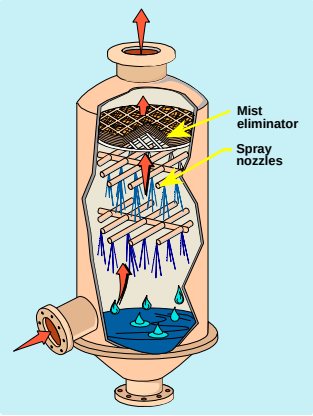
Condensers

Types of Condensation Systems

- Conventional systems
- Refrigeration systems
- Cryogenic systems

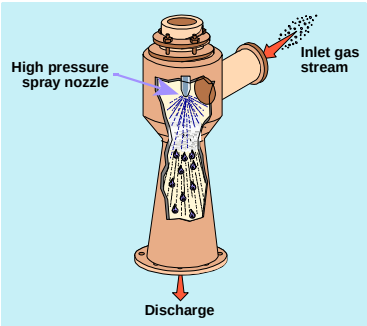
Types of Condensers

- Direct contact condensers
- Surface condensers

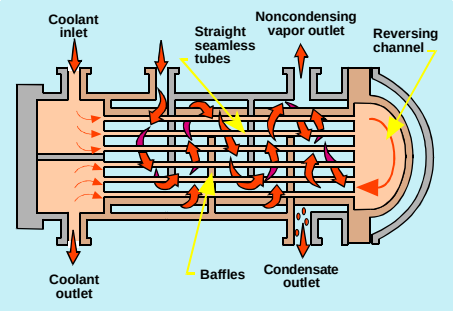


Direct Contact Condenser

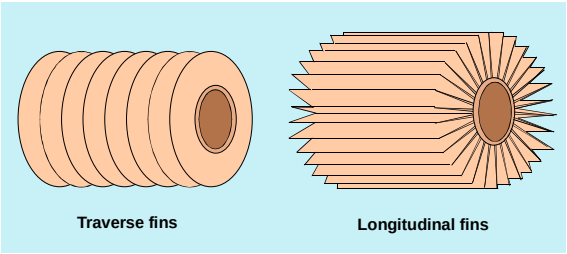
Ejector Condenser



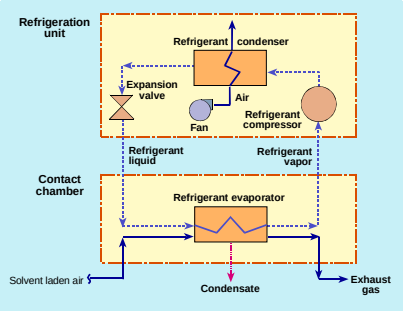
Shell and Tube Condenser



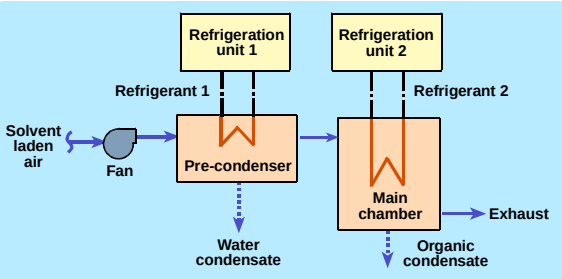
Tube and Fin Condenser



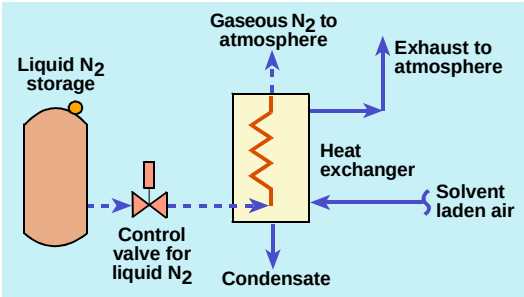
Refrigeration Cycle



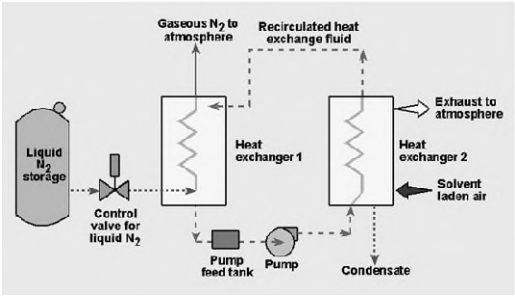
Refrigeration System



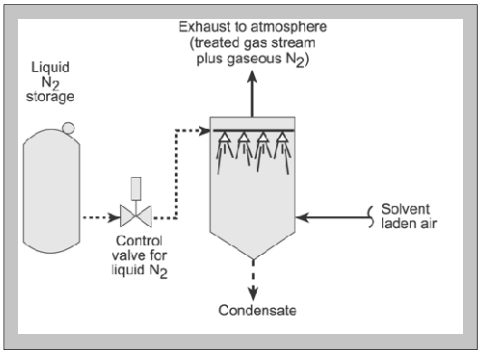
Single Heat Exchanger Cryogenic System



Dual Heat Exchanger Cryogenic System



Direct Contact Cryogenic Condenser



Compliance Inspection

General:

- Outlet gas temperature
- Coolant flow rate and temperature
- Condenser physical condition

Compliance Inspection

General:

- Outlet gas temperature
- Coolant flow rate and temperature
- Condenser physical condition

Compliance Inspection

General:

- Outlet gas temperature
- Coolant flow rate and temperature
- Condenser physical condition

Compliance Inspection

General:

- Outlet gas temperature
- Coolant flow rate and temperature
- Condenser physical condition

Compliance Inspection

Follow-up:

- Inlet concentration (%LEL) and hood static pressure
- Solvent recovery rates

Compliance Inspection

Follow-up:

- Inlet concentration (%LEL) and hood static pressure
- Solvent recovery rates

Compliance Inspection

Follow-up:

- Inlet concentration (%LEL) and hood static pressure
- Solvent recovery rates

Chapter 5

Nitrogen Oxides Control Systems

NO_X Formation Mechanisms

- Thermal NO_X
  Formed by oxidation of nitrogen in the combustion air
- Fuel NO_X
  Formed by oxidation of nitrogen in the fuel
- Prompt NO_X
  Formed by early free-radial reactions in the flame

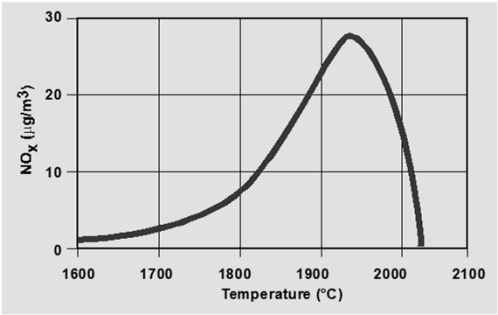
Thermal NO_x Formation

$$N_2 + O_2 \leftrightarrow 2NO$$

$$NO + \tfrac{1}{2} O_2 \leftrightarrow NO_2$$

Factors Affecting Thermal NO_X Formation

- Flame Temperature
- Residence time of combustion gases in peak temperature zone of the flame
- Amount of oxygen present in peak temperature zone of the flame



Techniques for Reducing Thermal NO_x

- Reduce peak flame temperature
- Reduce residence time at peak flame temperature
- Reduce oxygen concentration in maximum temperature zone

Fuel NO_x Formation

- Occurs by oxidation of organically bound nitrogen contained in the fuel
  - Coal: 0.2-3.5 weight percent
  - Fuel oil: 0.01-0.5 weight percent
  - Natural gas: None
- Approximately 20-60% of the fuel nitrogen is oxidized
- Amount oxidized decreases as nitrogen content increases

Factors Affecting Fuel NO_x Formation

- Combustion zone temperature
- Oxygen levels in the vicinity of the flame
- Fuel nitrogen content

Techniques for Reducing Fuel NO_X Formation

- Decrease combustion temperature
- Decrease oxygen concentration
- Decrease fuel nitrogen content

Prompt NO_x Formation

- Forms early in the combustion process due to free-radial reactions in the flame
- Residence time is usually too short to generate high concentrations
- Mechanism has greatest impact in fuel rich combustion zones
- Mechanism is of minor importance in large-scale combustion systems

Reducing Prompt NO_X

Prompt reactions are not sensitive to peak gas temperatures. Therefore, combustion modifications do not have a strong influence on the NO_X formed by this mechanism.

NO_x Control Systems

- Combustion modifications
- Fuel switching
- Add-on control devices

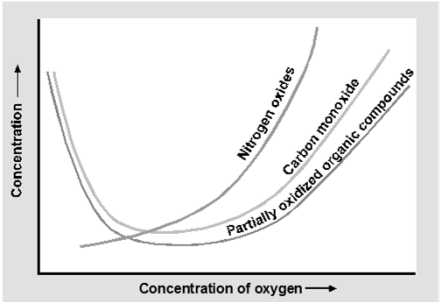
Boiler Combustion Modifications

- Low excess air combustion
- Off-stoichiometric combustion
- Flue gas recirculation
- Low NO_x burners
- Gas reburning

Boiler Combustion Modifications

- Low excess air combustion
- Off-stoichiometric combustion
- Flue gas recirculation
- Low NO_x burners
- Gas reburning

Effect of Oxygen on NO_x Formation



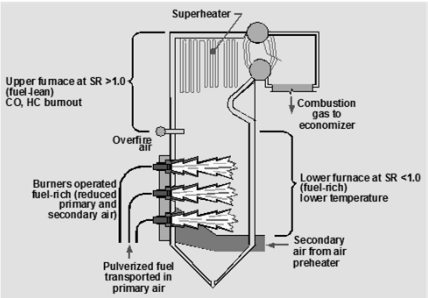
NO_x Reduction with Low Excess Air Combustion

- 16-20% for gas- and oil-fired boilers with 2-7% excess air
- ~20% for coal-fired boilers with 20% excess air

Off-Stoichiometric Combustion

- Combustion occurs in two zones
  - A primary zone with less than stoichiometric air (fuel rich)
  - A secondary zone where the remaining combustion air is added (air rich)

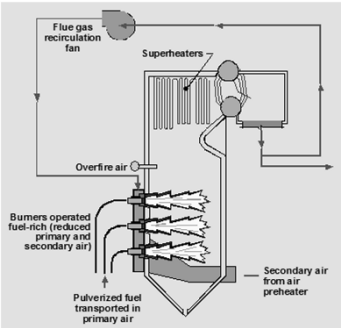
Use of Overfire Air (OFA)



NO_x Reduction with Off-Stoichiometric Combustion

- 30-40% for gas- and oil-fired boilers
- 30-50% for coal-fired boilers

Flue Gas Recirculaton (FGR)



NO_x Reduction with Flue Gas Recirculation

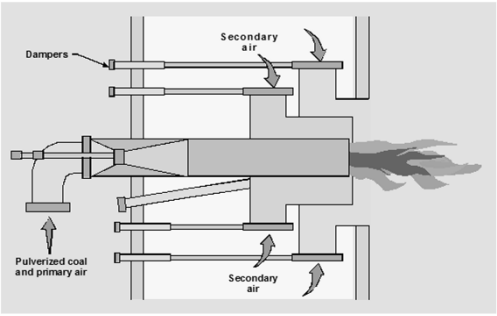
40-50% with recirculation of 20-30% of the exhaust gas in gas- and oil-fired boilers

Low NO_X Burners

Control techniques

- Low excess air
- Off-stoichiometric combustion
- Combustion gas recirculation

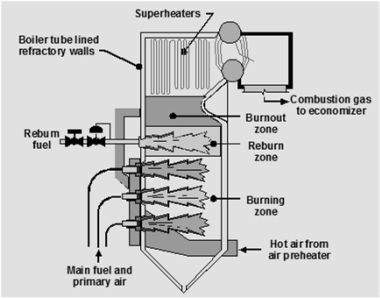
Dual Register Burner



NO_x Reduction with Low NO_x Burners

Typically, 25-60%. Ultra Low NO_x Burners have efficiencies approaching 80% and outlet concentrations less than 10 ppmv

Gas Reburning



NO_x Reduction with Gas Reburning

Reductions of 50-70% have been demonstrated at full boiler load

Gas Turbine Combustion Modifications

- Lean, pre-mixed combustors
- Rich/quench/lean combustors
- Water or steam injection

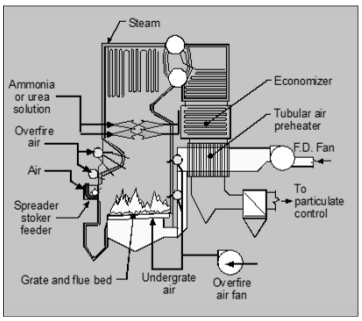
Fuel Switching

- Coal nitrogen content
- Fuel substitution
- Gas co-firing

Flue Gas Treatment

- Selective non-catalytic reduction (SNCR)
- Selective catalytic reduction (SCR)

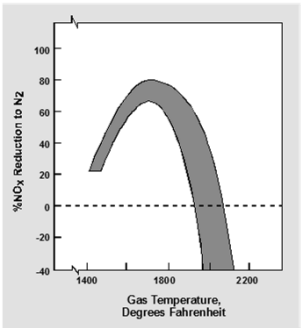
Selective Non-Catalytic Reduction

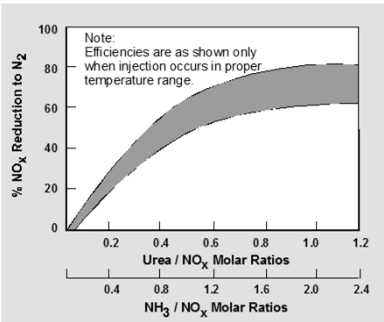


SNCR Reactions

$$4NH_3 + 4NO + O_2 \rightarrow 4N_2 + 6H_2O$$

$$2NO + NH_2CONH_2 + 0.5O_2 \rightarrow 2N_2 + 2H_2O + CO_2$$

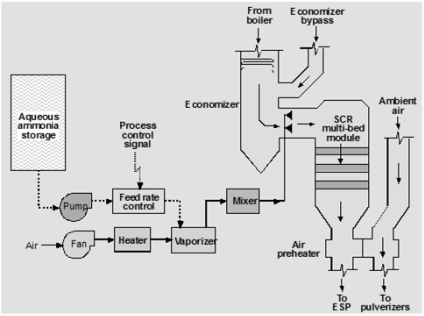




NO_x Reduction with SNCR

Typical reduction efficiencies for SNCR systems are 20-60%

Selective Catalytic Reduction

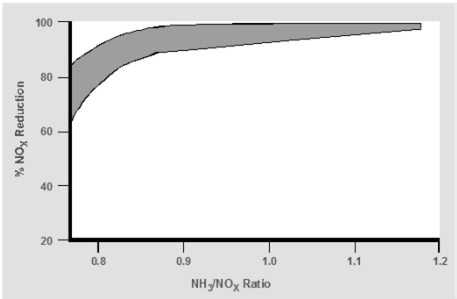


SCR Reactions

$$4NH_3 + 4NO + O_2 \xrightarrow{\text{Catalyst}} 4N_2 + 6H_2O$$

$$4NH_3 + 2NO_2 + O_2 \xrightarrow{\text{Catalyst}} 3N_2 + 6H_2O$$

Temperature range: 550-750°F



Catalyst Materials

- Noble metals (e.g., platinum, palladium, rhodium)
- Vanadium pentoxide
- Titanium dioxide
- Tungsten trioxide

Sulfur Dioxide Oxidation

$$2SO_2 + O_2 \xrightarrow{\text{catalyst}} 2SO_3$$

Formation of Sulfate Compounds

$$SO_3 + NH_3 + H_2O \longrightarrow NH_4HSO_4$$

$$SO_3 + 2NH_3 + H_2O \longrightarrow (NH_4)_2SO_4$$

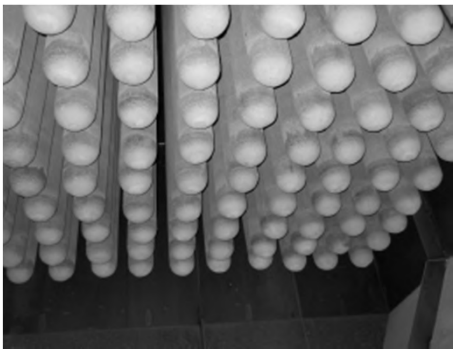
Common Catalyst Problems

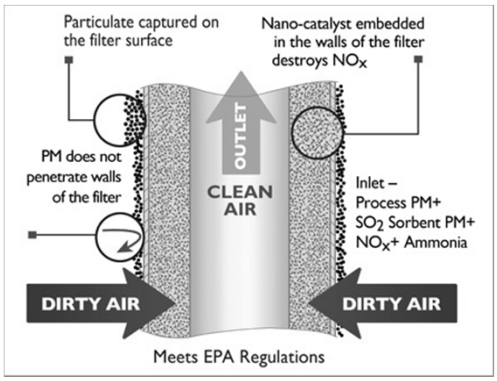
- Poisoning
- Fouling
- Masking
- Sintering
- Erosion

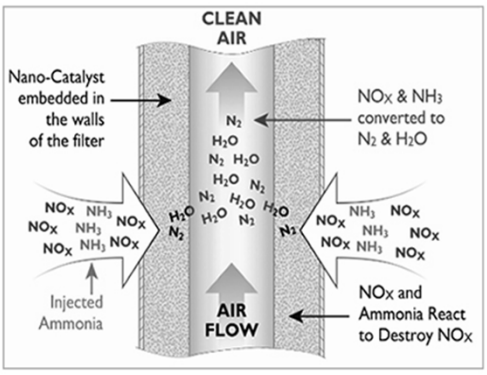
NO_x Reduction with SCR

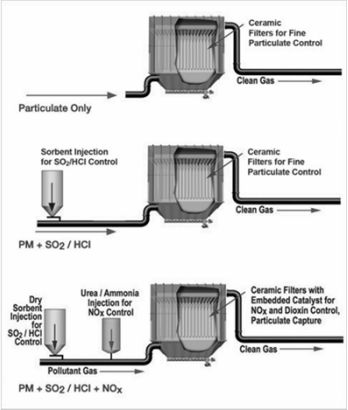
- Typical reduction efficiencies for SCR systems are 60-90%
- Some gas turbines have outlet concentrations less than 4 ppm corrected to 15% oxygen

Ceramic Catalyst Filter









General Range of NO_X Efficiencies

Control Technique	Typical Applications	NO_X Reduction Efficiencies, %
Combustion Modifications		
Low Excess Air	Coal-Fired Boilers, Municipal Waste Incinerators	15-30%
Off-Stoichiometric Combustion	Coal-, Oil-, Gas-Fired Boilers	15-50%
Flue Gas Recirculation	Coal-, Oil- Gas-Fired Boilers	15-50%
Low NO_X Burners	Coal-, Oil-, Gas-Fired Boilers	25-40%
Gas Reburning	Coal-, Oil-, Gas-Fired Boilers	30-70%
Lean Combustors	Gas-Fired Turbines	>90%
Water/Steam Injection	Gas-Fired Turbines	60-75%
Flue Gas Treatment		
SNCR	Coal-Fired Boilers, Municipal Waste Incinerators	20-60%
SCR	Coal-Fired Boilers, Gas Turbines	60-90%
Fuel Switching		
Low Nitrogen Coal	Coal-Fired Boilers	No Data
Co-Firing	Coal-Fired Boilers	No Data

Compliance Inspection

- Nitrogen oxides CEM data
- Visible emissions
- Gas temperatures
- Reagent feed rates and pressures
- SCR static pressure drop
- Gas turbine water or steam flow rates

Compliance Inspection

- Nitrogen oxides CEM data
- Visible emissions
- Gas temperatures
- Reagent feed rates and pressures
- SCR static pressure drop
- Gas turbine water or steam flow rates

Compliance Inspection

- Nitrogen oxides CEM data
- Visible emissions
- Gas temperatures
- Reagent feed rates and pressures
- SCR static pressure drop
- Gas turbine water or steam flow rates

Compliance Inspection

- Nitrogen oxides CEM data
- Visible emissions
- Gas temperatures
- Reagent feed rates and pressures
- SCR static pressure drop
- Gas turbine water or steam flow rates

Compliance Inspection

- Nitrogen oxides CEM data
- Visible emissions
- Gas temperatures
- Reagent feed rates and pressures
- SCR static pressure drop
- Gas turbine water or steam flow rates

Compliance Inspection

- Nitrogen oxides CEM data
- Visible emissions
- Gas temperatures
- Reagent feed rates and pressures
- SCR static pressure drop
- Gas turbine water or steam flow rates

Compliance Inspection

- Nitrogen oxides CEM data
- Visible emissions
- Gas temperatures
- Reagent feed rates and pressures
- SCR static pressure drop
- Gas turbine water or steam flow rates

Chapter 6

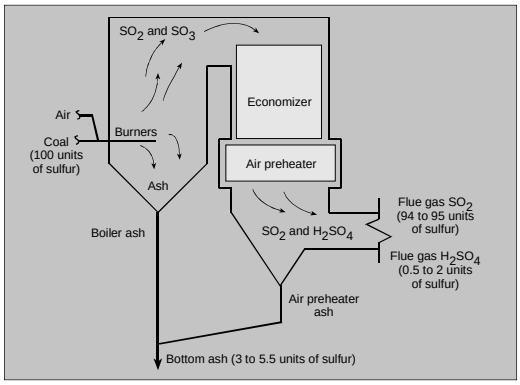
Sulfur Oxides Control Systems

Sulfur Oxides Formation Mechanisms

$$S + O_2 \rightarrow SO_2$$

$$S + 1.5\ O_2 \rightarrow SO_3$$

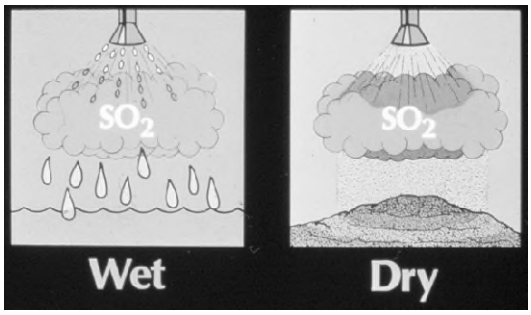
$$SO_3 + H_2O \rightarrow H_2SO_4$$



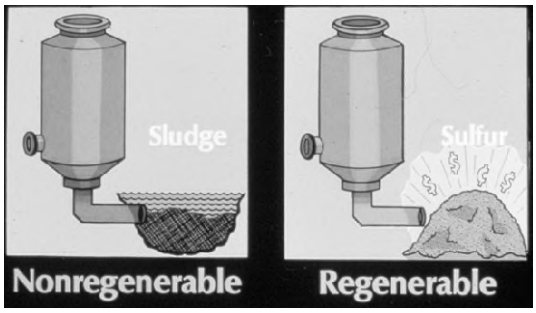
SO_x Control Systems

- Flue gas desulfurization
- Fuel treatment
- Low sulfur fuel firing

Flue Gas Desulfurization (FGD)



Wet FGD Systems



Non-Regenerative FGD Systems

Wet Systems:

Limestone	50%
Lime	20%
Dual-Alkali	3%

Dry Systems:

Lime Spray Dryer	8%

Regenerative FGD Systems

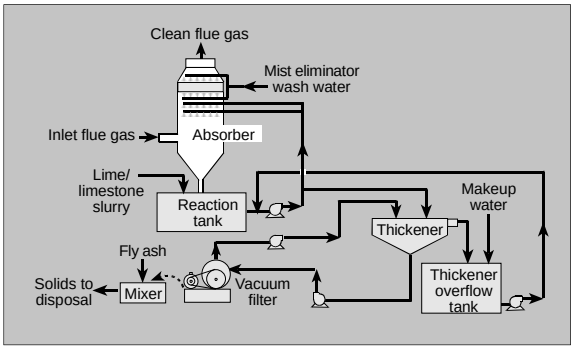
Wet Systems:

Limestone	4%
Wellman-Lord	3%

Limestone Scrubbing

$$SO_2 + CaCO_3 \rightarrow CaSO_3 + CO_2$$

$$CaSO_3 + 0.5O_2 \rightarrow CaSO_4$$



Lime Scrubbing

$$SO_2 + Ca(OH)_2 \rightarrow CaSO_3 + H_2O$$

$$CaSO_3 + 0.5O_2 \rightarrow CaSO_4$$

Reagent Preparation

$$CaCO_3 \xrightarrow{\Delta} CaO + CO_2$$

$$CaO + H_2O \rightarrow Ca(OH)_2$$

Dual Alkali Scrubbing

Absorption Reactions:

$$SO_2 + Na_2SO_3 + H_2O \rightarrow 2NaHSO_3$$

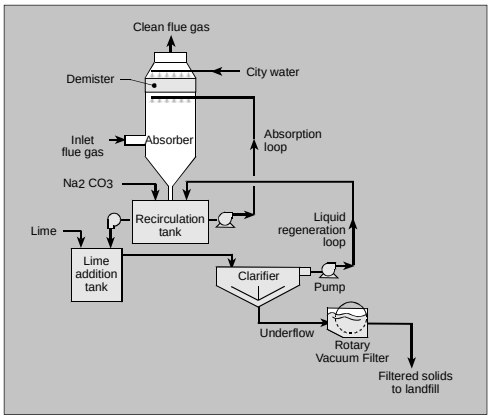
$$NaHSO_3 + 0.5O_2 \rightarrow NaHSO_4$$

Dual Alkali Scrubbing

Regeneration Reactions:

$$2NaHSO_3 + Ca(OH)_2 \rightarrow Na_2SO_3 + CaSO_3 + 2H_2O$$

$$NaHSO_4 + Ca(OH)_2 \rightarrow NaOH + CaSO_3 + H_2O$$



Wellman-Lord Process

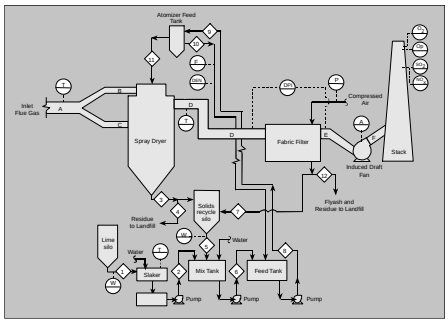
Absorption Reaction:

$$SO_2 + Na_2SO_3 + H_2O \rightarrow 2NaHSO_3$$

Regeneration Reaction:

$$2NaHSO_3 \rightarrow Na_2SO_3 + H_2O + SO_2$$

Spray Dryer Dry Scrubbing



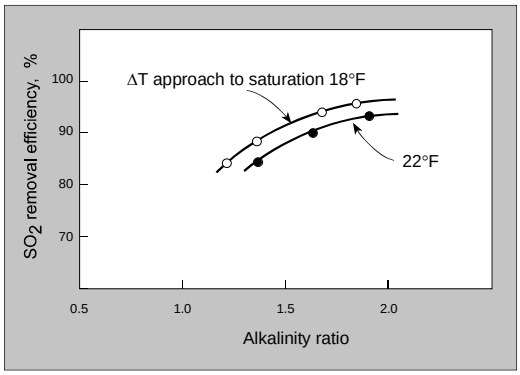
Types of Atomizers

- Rotary atomizers
- Compressed air assisted nozzles

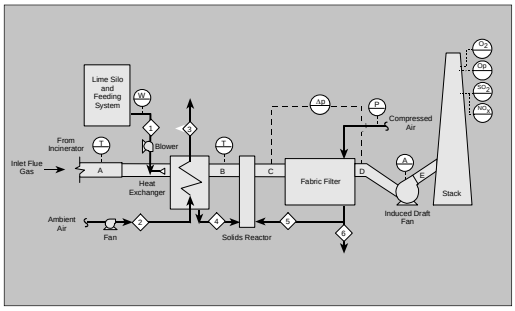
Acid Gas Removal Reactions

$$SO_2 + Ca(OH)_2 \rightarrow CaSO_3 + H_2O$$

$$2HCl + Ca(OH)_2 \rightarrow CaCl_2 + 2H_2O$$



Dry Injection Dry Scrubbing



Fluidized Bed Combustion

Fuel Treatment

- Coal gasification
- Coal liquefaction
- Coal cleaning
  - Physical methods
  - Chemical methods

SO_x Control Systems

- Flue gas desulfurization
- Fuel treatment
- Low sulfur fuel firing

Compliance Inspection

General:

- Sulfur oxides CEM data
- pH and alkalinity of scrubbing liquid
- Alkali feed rates
- Inlet and outlet temperatures
- Visible emissions
- Physical condition

Compliance Inspection

General:

- Sulfur oxides CEM data
- pH and alkalinity of scrubbing liquid
- Alkali feed rates
- Inlet and outlet temperatures
- Visible emissions
- Physical condition

Compliance Inspection

General:

- Sulfur oxides CEM data
- pH and alkalinity of scrubbing liquid
- Alkali feed rates
- Inlet and outlet temperatures
- Visible emissions
- Physical condition

Compliance Inspection

General:

- Sulfur oxides CEM data
- pH and alkalinity of scrubbing liquid
- Alkali feed rates
- Inlet and outlet temperatures
- Visible emissions
- Physical condition

Compliance Inspection

General:

- Sulfur oxides CEM data
- pH and alkalinity of scrubbing liquid
- Alkali feed rates
- Inlet and outlet temperatures
- Visible emissions
- Physical condition

Compliance Inspection

General:

- Sulfur oxides CEM data
- pH and alkalinity of scrubbing liquid
- Alkali feed rates
- Inlet and outlet temperatures
- Visible emissions
- Physical condition

Compliance Inspection

General:

- Sulfur oxides CEM data
- pH and alkalinity of scrubbing liquid
- Alkali feed rates
- Inlet and outlet temperatures
- Visible emissions
- Physical condition

Compliance Inspection

Follow-up:

- Mist eliminator static pressure drop
- Slurry atomizer conditions
- Flue gas oxygen concentration

Compliance Inspection

Follow-up:

- Mist eliminator static pressure drop
- Slurry atomizer conditions
- Flue gas oxygen concentration

Compliance Inspection

Follow-up:

- Mist eliminator static pressure drop
- Slurry atomizer conditions
- Flue gas oxygen concentration

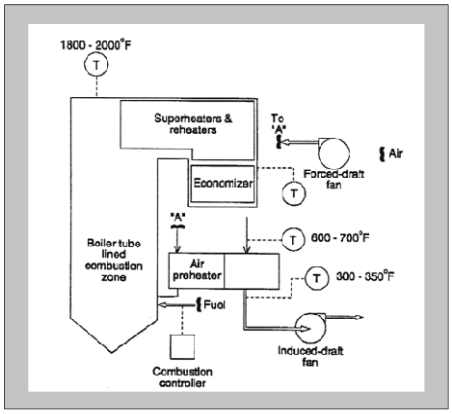
Compliance Inspection

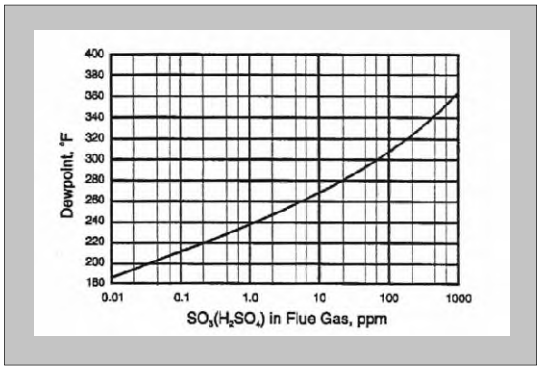
Follow-up:

- Mist eliminator static pressure drop
- Slurry atomizer conditions
- Flue gas oxygen concentration

Chapter 7

Utility and Industrial Boilers

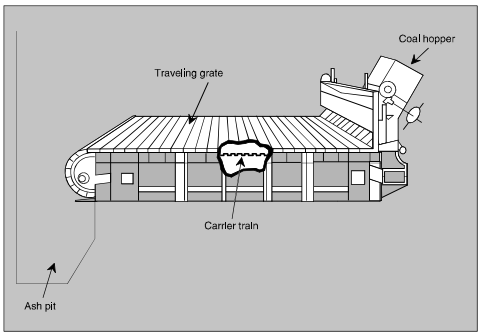




Combustion Units

- Solid-fuel combustors
  - Overfeed stoker
  - Spreader stoker
  - Pulverized coal combustor
- Liquid-fuel combustors

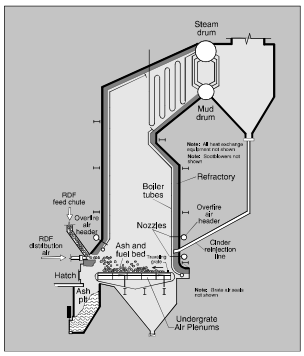
Overfeed Stokers



Characteristics of Overfeed Stokers

- 20,000-150,000 pounds of steam per hour
- Not capable of rapid load changes
- Free-swell index should be less than 5 (without tempering)
- Ash fusion temperature should be greater than 1,900°F
- Ash content should be greater than 5-6%

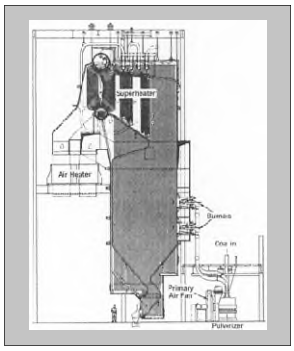
Spreader Stokers



Characteristics of Spreader Stokers

- 40,000-400,000 pounds of steam per hour
- Capable of rapid load changes
- Free-swell index should be less than 5 (without tempering)
- Ash fusion temperature should be greater than 1,900°F
- Ash content should be greater than 5-6%
- Typical loss-on-ignition (LOI) is 10-50%

Pulverized Coal-Fired Boiler



Burner Arrangements

- Front-fired
- Opposed-fired (front and back walls)
- Tangential-fired (four corners)

Characteristics of Pulverized Coal Boilers

- Large industrial boilers and utility power stations
- Capable of rapid load changes
- Feed coal size to pulverizer not important
- Free-swell index not important
- Ash fusion temperature determines bottom ash recovery method
- Typical loss-on-ignition (LOI) is 0.5-5%

Combustion Units

- Solid-fuel combustors
  - Overfeed stoker
  - Spreader stoker
  - Pulverized coal combustor
- Liquid-fuel combustors

Compliance Inspection

- Fuel characteristics
- Firing conditions
- Ash characteristics

Compliance Inspection

Fuel Characteristics

- Type(s) of fuels
- Ultimate analysis (S, N, Cl, ash)
- Proximate analysis
- Ash composition
- Fuel sizing
- Ash fusion temperature
- Free-swell index

Compliance Inspection

Fuel Characteristics

- Type(s) of fuels
- Ultimate analysis (S, N, Cl, ash)
- Proximate analysis
- Ash composition
- Fuel sizing
- Ash fusion temperature
- Free-swell index

Types of Wood Waste

- Bark
- Dimensional lumber
- Chips
- Sawdust
- Sander dust

Compliance Inspection

Fuel Characteristics

- Type(s) of fuels
- Ultimate analysis (S, N, Cl, ash)
- Proximate analysis
- Ash composition
- Fuel sizing
- Ash fusion temperature
- Free-swell index

Compliance Inspection

Fuel Characteristics

- Type(s) of fuels
- Ultimate analysis (S, N, Cl, ash)
- Proximate analysis
- Ash composition
- Fuel sizing
- Ash fusion temperature
- Free-swell index

Proximate Analysis

- Heating value, Btu/pound
- Moisture content, percent
- Volatile matter content, percent
- Fixed carbon content, percent
- Ash content, percent

Compliance Inspection

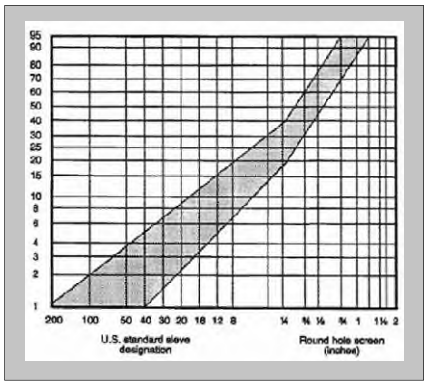
Fuel Characteristics

- Type(s) of fuels
- Ultimate analysis (S, N, Cl, ash)
- Proximate analysis
- Ash composition
- Fuel sizing
- Ash fusion temperature
- Free-swell index

Compliance Inspection

Fuel Characteristics

- Type(s) of fuels
- Ultimate analysis (S, N, Cl, ash)
- Proximate analysis
- Ash composition
- Fuel sizing
- Ash fusion temperature
- Free-swell index



Compliance Inspection

Fuel Characteristics

- Type(s) of fuels
- Ultimate analysis (S, N, Cl, ash)
- Proximate analysis
- Ash composition
- Fuel sizing
- Ash fusion temperature
- Free-swell index

Compliance Inspection

Fuel Characteristics

- Type(s) of fuels
- Ultimate analysis (S, N, Cl, ash)
- Proximate analysis
- Ash composition
- Fuel sizing
- Ash fusion temperature
- Free-swell index

Compliance Inspection

Firing Conditions

- Load
- Oxygen concentrations
- CO concentrations
- Air infiltration
- Overfire and underfire air flow rates
- Soot blowing practices
- Fuel/air distribution
- Boiler draft

Compliance Inspection

Firing Conditions

- Load
- Oxygen concentrations
- CO concentrations
- Air infiltration
- Overfire and underfire air flow rates
- Soot blowing practices
- Fuel/air distribution
- Boiler draft

Compliance Inspection

Firing Conditions

- Load
- Oxygen concentrations
- CO concentrations
- Air infiltration
- Overfire and underfire air flow rates
- Soot blowing practices
- Fuel/air distribution
- Boiler draft

Compliance Inspection

Firing Conditions

- Load
- Oxygen concentrations
- CO concentrations
- Air infiltration
- Overfire and underfire air flow rates
- Soot blowing practices
- Fuel/air distribution
- Boiler draft

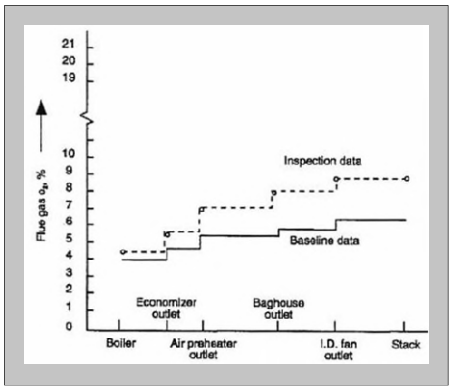
Causes of Higher CO Concentrations

- Overcharging of moist fuels
- Air infiltration related cooling of the combustion area
- Inadequate oxygen
- Poor air/fuel distribution
- Inadequate overfire air
- Operation at low load

Compliance Inspection

Firing Conditions

- Load
- Oxygen concentrations
- CO concentrations
- Air infiltration
- Overfire and underfire air flow rates
- Soot blowing practices
- Fuel/air distribution
- Boiler draft



Compliance Inspection

Firing Conditions

- Load
- Oxygen concentrations
- CO concentrations
- Air infiltration
- Overfire and underfire air flow rates
- Soot blowing practices
- Fuel/air distribution
- Boiler draft

Compliance Inspection

Firing Conditions

- Load
- Oxygen concentrations
- CO concentrations
- Air infiltration
- Overfire and underfire air flow rates
- Soot blowing practices
- Fuel/air distribution
- Boiler draft

Compliance Inspection

Firing Conditions

- Load
- Oxygen concentrations
- CO concentrations
- Air infiltration
- Overfire and underfire air flow rates
- Soot blowing practices
- Fuel/air distribution
- Boiler draft

Compliance Inspection

Firing Conditions

- Load
- Oxygen concentrations
- CO concentrations
- Air infiltration
- Overfire and underfire air flow rates
- Soot blowing practices
- Fuel/air distribution
- Boiler draft

Compliance Inspection

Ash Characteristics

- LOI and appearance
- Fugitive emissions

Compliance Inspection

Ash Characteristics

- LOI and appearance
- Fugitive emissions

Compliance Inspection

Ash Characteristics

- LOI and appearance
- Fugitive emissions

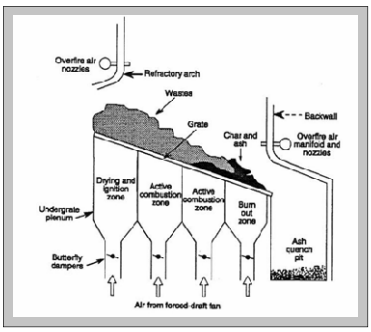
Chapter 8

Municipal and Medical Waste Incinerators

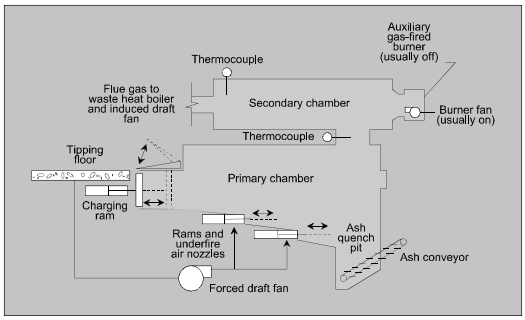
Combustion Units

- Reciprocating grate incinerators
- Modular incinerators
- Rotary kilns

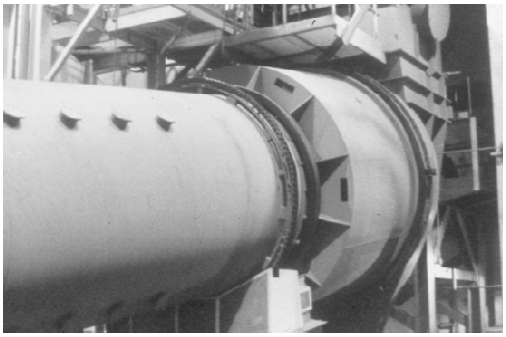
Reciprocating Grate Incinerator

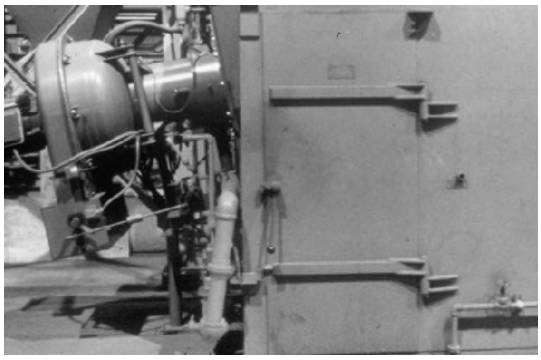


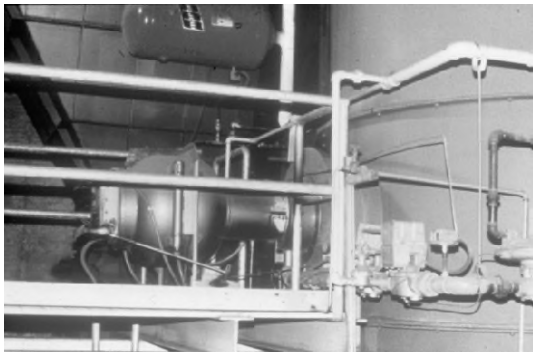
Modular Incinerator



Rotary Kiln







Compliance Inspection

- Waste characteristics
- Firing conditions
- Ash characteristics

Compliance Inspection

Waste Characteristics

- Type(s) of wastes burned

Undesirable Incinerator Wastes

- Hazardous chemicals
- Asbestos containing materials
- Flammable liquids (gasoline cans, solvent-based paints)
- Bulky furniture, appliances or automobile parts
- Cables and/or rolls or agricultural plastics
- Animal carcasses
- Pressurized cylinders

Compliance Inspection

Firing Conditions

- Load
- Combustion chamber temperatures
- Oxygen concentrations
- CO concentrations
- Air infiltration
- Incinerator draft
- Overfire and underfire air flow rates

Compliance Inspection

Firing Conditions

- Load
- Combustion chamber temperatures
- Oxygen concentrations
- CO concentrations
- Air infiltration
- Incinerator draft
- Overfire and underfire air flow rates

Compliance Inspection

Firing Conditions

- Load
- Combustion chamber temperatures
- Oxygen concentrations
- CO concentrations
- Air infiltration
- Incinerator draft
- Overfire and underfire air flow rates

Compliance Inspection

Firing Conditions

- Load
- Combustion chamber temperatures
- Oxygen concentrations
- CO concentrations
- Air infiltration
- Incinerator draft
- Overfire and underfire air flow rates

Compliance Inspection

Firing Conditions

- Load
- Combustion chamber temperatures
- Oxygen concentrations
- CO concentrations
- Air infiltration
- Incinerator draft
- Overfire and underfire air flow rates

Causes of Higher CO Concentrations

- Overcharging of moist fuels
- Air infiltration related cooling of the combustion area
- Inadequate oxygen
- Poor air/waste distribution
- Inadequate overfire air
- Operation at low load

Compliance Inspection

Firing Conditions

- Load
- Combustion chamber temperatures
- Oxygen concentrations
- CO concentrations
- Air infiltration
- Incinerator draft
- Overfire and underfire air flow rates

Compliance Inspection

Firing Conditions

- Load
- Combustion chamber temperatures
- Oxygen concentrations
- CO concentrations
- Air infiltration
- Incinerator draft
- Overfire and underfire air flow rates

Compliance Inspection

Firing Conditions

- Load
- Combustion chamber temperatures
- Oxygen concentrations
- CO concentrations
- Air infiltration
- Incinerator draft
- Overfire and underfire air flow rates

Compliance Inspection

Ash Characteristics

- LOI and appearance
- Fugitive emissions

Compliance Inspection

Ash Characteristics

- LOI and appearance
- Fugitive emissions

Compliance Inspection

Ash Characteristics

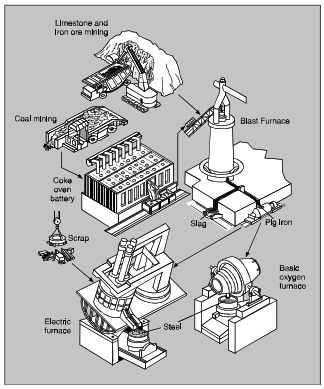
- LOI and appearance
- Fugitive emissions

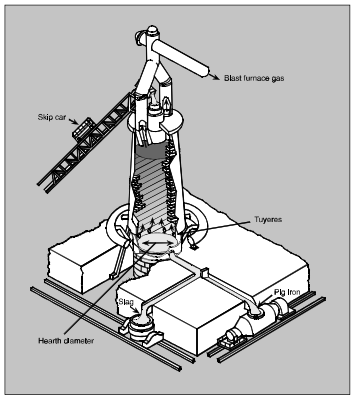
Chapter 9

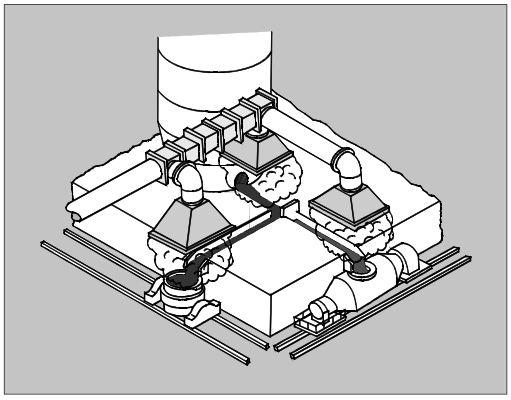
Iron and Steel Processes

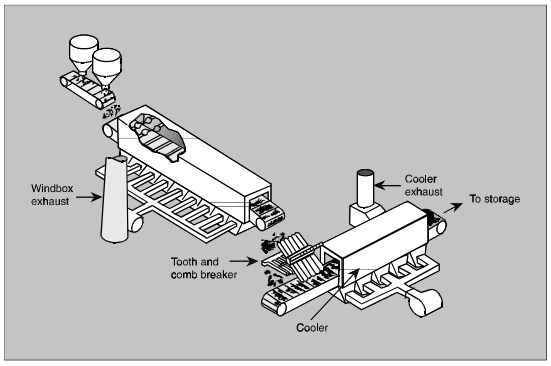
General Inspection Items

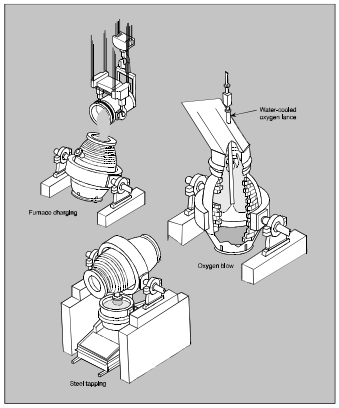
- Process operating rates
- Quality and types of materials processed
- Fugitive emissions

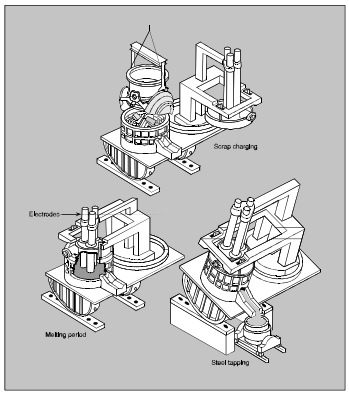


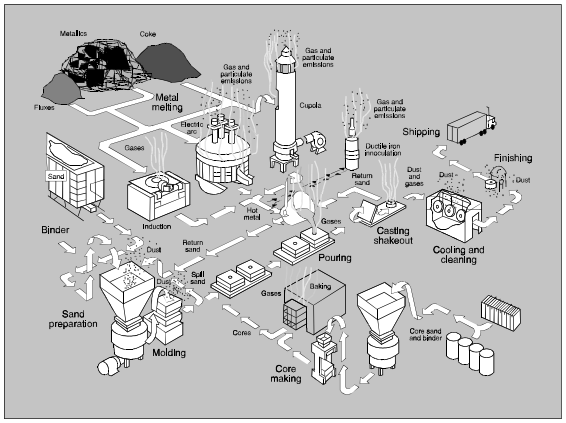

Blast furnace gas
Skip car
Tuyeres
Slag
Pig iron
Hearth diameter




Windbox exhaust
Cooler exhaust
To storage
Tooth and comb breaker
Cooler


Water-cooled oxygen lance
Furnace charging
Oxygen blow
Steel tapping


Scrap charging
Electrodes
Melting period
Steel tapping


Metallics
Coke
Fluxes
Metal melting
Gas and particulate emissions
Gas and particulate emissions
Cupola
Gas and particulate emissions
Shipping
Electric arc
Gases
Ductile iron inoculation
Finishing
Sand
Return sand
Dust and gases
Dust
Dust
Hot metal
Gases
Binder
Induction
Casting shakeout
Cooling and cleaning
Return sand
Dust
Pouring
Soil sand
Dust
Gases
Baking
Sand preparation
Cores
Core sand and binder
Molding
Core making

Inspection Issues

- Is the process operating in accordance with the operating permit limitations and with applicable regulations?
- Are fugitive emissions being adequately captured?
- Have operating conditions changed and created potential problems for the air pollution control system?

Compliance Inspection

- Operating procedures
- Emissions
- Emission capture system

Compliance Inspection

Operating Procedures

- Quality of scrap charged
- Oxygen injection
- Operating rate

Compliance Inspection

Operating Procedures

- Quality of scrap charged
- Oxygen injection
- Operating rate

Compliance Inspection

Operating Procedures

- Quality of scrap charged
- Oxygen injection
- Operating rate

Compliance Inspection

Operating Procedures

- Quality of scrap charged
- Oxygen injection
- Operating rate

Compliance Inspection

Emissions

- Fugitive emission observations
- Opacity monitoring data

Compliance Inspection

Emissions

- Fugitive emission observations
- Opacity monitoring data

Compliance Inspection

Emissions

- Fugitive emission observations
- Opacity monitoring data

Compliance Inspection

Emission Capture System

- Hood position and condition
- Gas flow rate
- Inlet gas temperature
- Hood static pressure

Compliance Inspection

Emission Capture System

- Hood position and condition
- Gas flow rate
- Inlet gas temperature
- Hood static pressure

Hood Effectiveness Factors

- Position of the hood relative to the source of emissions
- Cross drafts or other factors interfering with capture
- Physical condition of the hood
- Capture velocities at the hood

Compliance Inspection

Emission Capture System

- Hood position and condition
- Gas flow rate
- Inlet gas temperature
- Hood static pressure

Compliance Inspection

Emission Capture System

- Hood position and condition
- Gas flow rate
- Inlet gas temperature
- Hood static pressure

Compliance Inspection

Emission Capture System

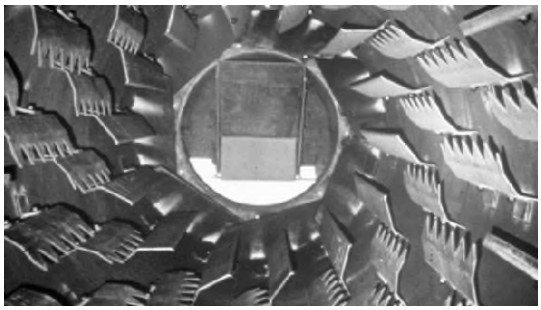
- Hood position and condition
- Gas flow rate
- Inlet gas temperature
- Hood static pressure

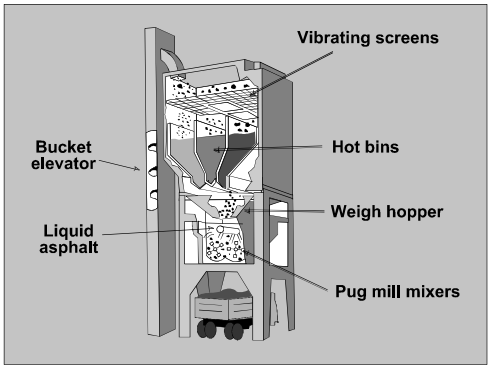
Chapter 10

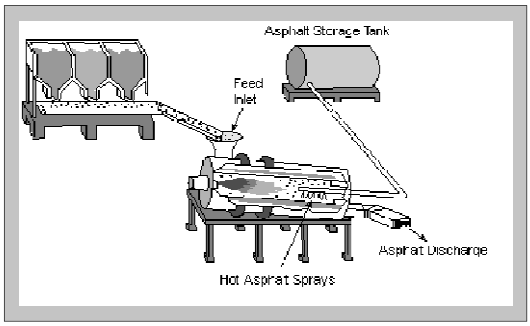
Asphalt Plants

Types of Asphalt Plants

- Hot mix
- Drum mix




Vibrating screens
Bucket elevator
Hot bins
Weigh hopper
Liquid asphalt
Pug mill mixers


Asphalt Storage Tank
Feed Inlet
Asphalt Discharge
Hot Asphalt Sprays

Minimizing Volatile Emissions

- Reduce the dryer aggregate temperature
- Shield the binder injection point from the radiant heat of the burner
- Move the binder injection pipe to a slightly cooler area within the drum
- Convert to a less volatile binder

Compliance Inspection

- Production rates
- Dryer aggregate temperature
- Binder type
- Dryer effluent gas temperature
- Fugitive emissions

Compliance Inspection

- Production rates
- Dryer aggregate temperature
- Binder type
- Dryer effluent gas temperature
- Fugitive emissions

Compliance Inspection

- Production rates
- Dryer aggregate temperature
- Binder type
- Dryer effluent gas temperature
- Fugitive emissions

Compliance Inspection

- Production rates
- Dryer aggregate temperature
- Binder type
- Dryer effluent gas temperature
- Fugitive emissions

Compliance Inspection

- Production rates
- Dryer aggregate temperature
- Binder type
- Dryer effluent gas temperature
- Fugitive emissions

Compliance Inspection

- Production rates
- Dryer aggregate temperature
- Binder type
- Dryer effluent gas temperature
- Fugitive emissions

Inspection of Gas Control Devices and Selected Industries

August 28-30, 2018

AGENDA

LOCATION	**MODERATOR**
Murfreesboro, Tennessee	J.W. Crowder

DAY & TIME	SUBJECT	SPEAKER
Tuesday, August 28		
9:00	Introduction	J. Crowder
9:15	Pre-Test	
9:45	BREAK	
10:00	Review of the Baseline Inspection Technique	J. Crowder
11:00	Inspection of Carbon Adsorbers	J. Crowder
12:00	LUNCH	
1:00	Inspection of Carbon Adsorbers (cont'd)	J. Crowder
1:45	Inspection of Thermal and Catalytic Oxidizers	J. Crowder
2:45	BREAK	
3:00	Inspection of Thermal and Catalytic Oxidizers (cont'd)	J. Crowder
3:30	Inspection of Condensers	J. Crowder
4:30	ADJOURN	
Wednesday, August 29		
9:00	Inspection of Nitrogen Oxide Control Systems	J. Crowder
10:15	BREAK	
10:30	Inspection of Sulfur Dioxide Control Systems	J. Crowder
12:00	LUNCH	
1:00	Inspection of Utility and Industrial Boilers	J. Crowder
2:45	BREAK	
3:00	Inspection of Waste Incinerators	J. Crowder
4:00	Review of Pre-Test	J. Crowder
4:30	ADJOURN	
Thursday, August 30		
9:00	Inspection of Iron and Steel Processes	J. Crowder
10:30	BREAK	
10:45	Inspection of Asphalt Plants	J. Crowder
12:00	LUNCH	
1:00	Post-Test	
2:30	Course Critique	
3:00	ADJOURN	

Jerry W. Crowder, Ph.D., P.E.
Crowder Environmental Associates, Inc.
120 Cherry Circle
Dyersburg, TN 38024
Tel: (731) 286-1554
Fax: (731) 286-4910
Cell: (731) 589-0911
E-mail: jwcrowder@cableone.net