Operation Of Thermal And Catalytic Incinerators

Introduction

Incinerators are used to control emissions from curing ovens, dryers, and other sources of organic vapors. They are often used when it is not economical to recover organic vapors, or when compliance cannot be achieved by using low-solvent coatings or inks. In some cases, incinerators have been installed to allow compliance with regulatory requirements until low-solvent coatings and inks can be developed.

Incinerators are relatively simple devices that efficiently destroy organic vapors. There are two major types—thermal and catalytic. Incinerators usually consist of one or more burners and a refractory-lined (heat-resistant) chamber. The burners supply the air and fuel needed to provide heat. In both thermal and catalytic incinerators, the VOC compounds are not oxidized within the burner flame itself; the burners provide turbulent mixing and hot gas, both of which are necessary to oxidize the VOCs. The chamber acts as a holding space that allows time for all vapors to oxidize. Incinerators often include a device or system to recover heat from the hot exhaust gases.

In incinerators, the burner provides turbulent mixing and hot gases necessary to allow the VOCs to oxidize.

Components And Operating Principles Of Incinerator Systems

In air pollution control systems, the function of the incinerator is to oxidize completely the organic gases and combustible particulate matter. If this combustion reaction is complete, the organic materials in the exhaust gases will have chemically reacted with O_2 in the combustion air to form nontoxic products, such as CO_2 and water vapor. When combustion is incomplete, new pollutants that might be more toxic or corrosive than the original are formed. To achieve complete combustion of any mixture, the pollutants must be heated to the proper temperature, turbulently mixed with sufficient O_2, and retained in the chamber long enough to allow combustion.

The ultimate function of incineration is to achieve complete combustion. Incomplete combustion can form new, potentially more toxic compounds.

Proper Operating Temperature

Thermal incinerators have a burner flame in the main chamber of the incinerator to generate hot combustion gas. This gas heats the relatively cool VOC-containing gas stream to the combustion temperature, which is several hundred degrees Fahrenheit above the **auto-ignition temperature**. The auto-ignition temperature is unique to each compound. It is the minimum temperature that must be reached before combustion can occur. This temperature generally ranges from 800 to 1400 °F.

The auto-ignition temperature is the minimum temperature that must be reached before combustion can occur.

In catalytic incinerators, preheater burners raise the gas stream temperature to the level neccessary to allow oxidation to be completed on the surface of the catalyst bed. Operating temperatures of catalytic incinerators are generally several hundred degrees lower than those of thermal incinerat rs for the same organic compounds because the catalyst promotes oxidation reactions.

Turbulence

Turbulence provides the mixing needed to bring the organic material and the O_2 together for oxidation and helps transfer heat between the hot combustion gases and the cooler VOC material.

Complete combustion can occur only if all organic molecules in the exhaust stream come in contact with O_2 molecules in the combustion air at temperatures above the auto-ignition temperature. Turbulence is important because it provides the mixing needed to bring the organic molecules and the O_2 together. Turbulence also helps transfer heat between the hot combustion gases and the cooler, VOC-containing gas stream. This heat transfer raises the temperature of the organic molecules above their auto-ignition temperature. The waste gas stream can be heated by direct contact with the auxiliary fuel flame and/or by mixing with the hot combustion products downstream of the flame.

Oxygen

Incinerators use excess air to ensure complete combustion. Too much excess air reduces incinerator temperature and incinerator removal efficiency.

To ensure complete combustion, essentially all industrial incinerators use more than the theoretical minimum amount (the **stoichiometric** amount) of O_2. (This extra volume of air is referred to as excess air.) The amount of excess air is usually kept low, because heating the excess air to the operating temperature of the incinerator requires additional fuel, which increases operating costs. In addition, extreme levels of excess air can reduce incinerator temperatures and, thus, reduce VOC removal efficiency.

Residence Time

Residence time is the length of time the gas remains in the high-temperature combustion zone.

Residence time in an incinerator is measured from the time the waste gas stream reaches the operating temperature, until the time the waste gas leaves the combustion chamber. The residence time, therefore, is determined by the size of the combustion chamber and the gas flow rate through the chamber.

VOC Concentration

VOC inlet concentrations are kept below 25 percent of the LEL.

For saftey reasons, inlet gas stream VOC concentrations for thermal a catalytic incinerators are usually limited to between 500 and 7,500 pp The VOC concentrations are kept below 25 percent of the Lower Explosive Limit (LEL) so that the incinerator flame does not flash back to the process equipment. The 25 percent LEL value is a widely accepted upper-concentration limit and allows for some nonuniformity and variability in the gas stream VOC levels. The concentrations corresponding to 25 percent of the LEL for a number of common organic chemicals are provided in

Table 9-1. When mixtures of organic compounds are present in the inlet gas stream, the total concentration is generally limited to 25 percent of the lowest LEL for the various compounds.

Some new incinerators can handle inlet concentrations of up to 50 percent of the LEL.

Incinerators that can operate safely with VOC concentrations of up to 50 percent of the LEL have recently been installed. These systems require continuous inlet VOC concentration monitors as a safety feature.

Table 9-1. VOC Concentrations Corresponding To 25 Percent Of LELs

VOC	Concentration (ppm)
Butane	4,750
Ethane	7,500
Ethylene	7,750
Propylene	6,000
Styrene	2,750
Benzene	3,500
Xylene	2,500
Toluene	3,500
Methyl alcohol	18,250
Isopropyl alcohol	5,000
Acetone	7,500
Methyl ethyl ketone	4,500
Methyl acetate	7,750
Cellosolve acetate	4,250
Acrolein	7,000
Cyclohexanone	2,750
Acetaldehyde	10,000
Furfural	5,250

Thermal Incinerators

The major components of a thermal incinerator include one or more sets of burners, a refractory-lined combustion chamber, and a stack. Figure 9-1 illustrates a typical burner and chamber in a direct-flame incinerator. The burner includes a combustion air supply controller, a fuel-rate controller, a flashback arrestor, and a burner assembly. A thermocouple on the incinerator discharge is often usec ɔ operate the controller, which maintains the proper air/fuel ratio. I:. some systems, heat recovery equipment is used on the incinerator discharge to preheat the incoming VOC-containing gas stream. This reduces operating costs. Figure 9-2 shows a typical system with a heat exchanger used to recover heat.

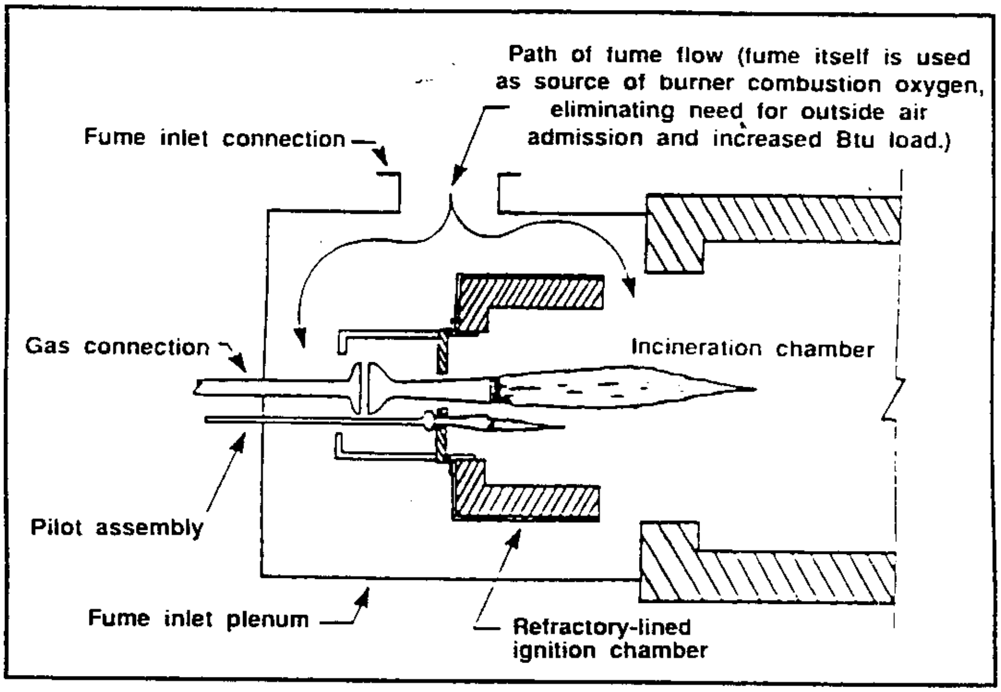

Figure 9-1. Direct-Flame Thermal Incinerator

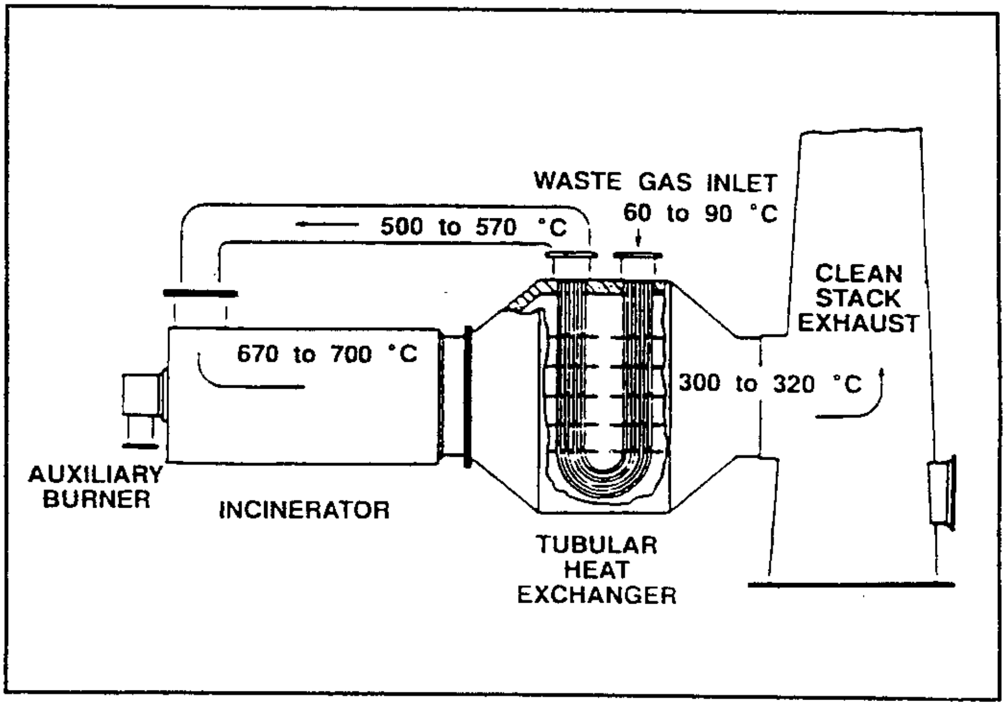

Figure 9-2. Direct-Flame Incinerator With Heat Exchanger

Burners using supplemental fuel usually operate when the incinerator is online because the VOC concentrations in the waste stream are too low to maintain combustion.

Where Do Most Problems With Thermal Incinerators Exist?

Most operation and maintenance problems associated with thermal incinerators concern the burner, because this component is subjected to extreme gas velocities and gas temperatures. These problems include poor fuel atomization (on oil-fired units), deposits within the burner that cause poor air-fuel mixing, inadequate air supply, and flame quenching on refractory surfaces. Routine maintenance is necessary to clean and readjust the burners for proper operation. Symptoms of poor burner performance include black smoke generation, lower-than-normal outlet temperatures, and higher-than-normal VOC outlet concentrations.

Most operation and maintenance problems of thermal incinerators are associated with the burner system.

Thermal incinerators are also subject to problems caused by rapidly varying VOC concentrations and gas flow rates. These variations change the fuel requirements necessary to maintain a stable outlet temperature. A sudden decrease in the VOC concentrations, coupled with increased waste gas flow rates, can lead to short-term periods of lower-than-desirable operating temperatures. A sharp increase in the VOC concentrations, along with a decreased gas flow rate, can lead to short-term excursions above the maximum temperature limits of the combustion chamber.

Varying VOC concentrations and gas flow rates can cause problems with incinerator performance.

Catalytic Incinerators

A catalyst is a substance that causes or speeds up a chemical reaction without undergoing a change itself. In catalytic incinerators, a waste gas is passed through a layer of catalyst—the catalyst bed. The catalyst causes the oxidation reaction to proceed at a faster rate and at a lower temperature than in thermal oxidation. A catalytic incinerator operating at temperatures from 370 to 480 °C (approx. 700 to 900 °F) can often achieve the same VOC removal efficiency as a thermal incinerator operating at 700 to 820 °C (approx. 1300 to 1500 °F).

What Types Of Catalysts Are Used?

The most commonly used catalysts for oxidation reactions come from the noble metals group (e.g., gold, silver, platinum). Because catalytic oxidation is a surface reaction, the noble metal is used to coat the surface of a cheaper support material, such as ceramic or nickel-chromium. Platinum, either alone or in combination with other noble metals, is the most commonly used catalyst. Palladium, another noble metal, is also used.

The most common catalysts come from the noble metals.

The basic components of a catalytic incinerator include the preheater burner, a mixing chamber, a catalyst bed, a heat recovery system, and a stack (Figure 9-3). The preheater burner is used whenever supplemental fuel is needed to achieve the necessary operating temperature. In many cases, the VOC contaminants have sufficient heat value to achieve the relatively low combustion temperatures without the preheater burners. Therefore, inspectors should not conclude that the unit is not operating

Preheater burners are used (when necessary) to achieve the required operating temperature.

correctly simply because the preheater burner is not operating at the time of the inspection. It is quite possible that the preheater burner is used only during startup or during periods of low-VOC concentrations in the inlet gas stream.

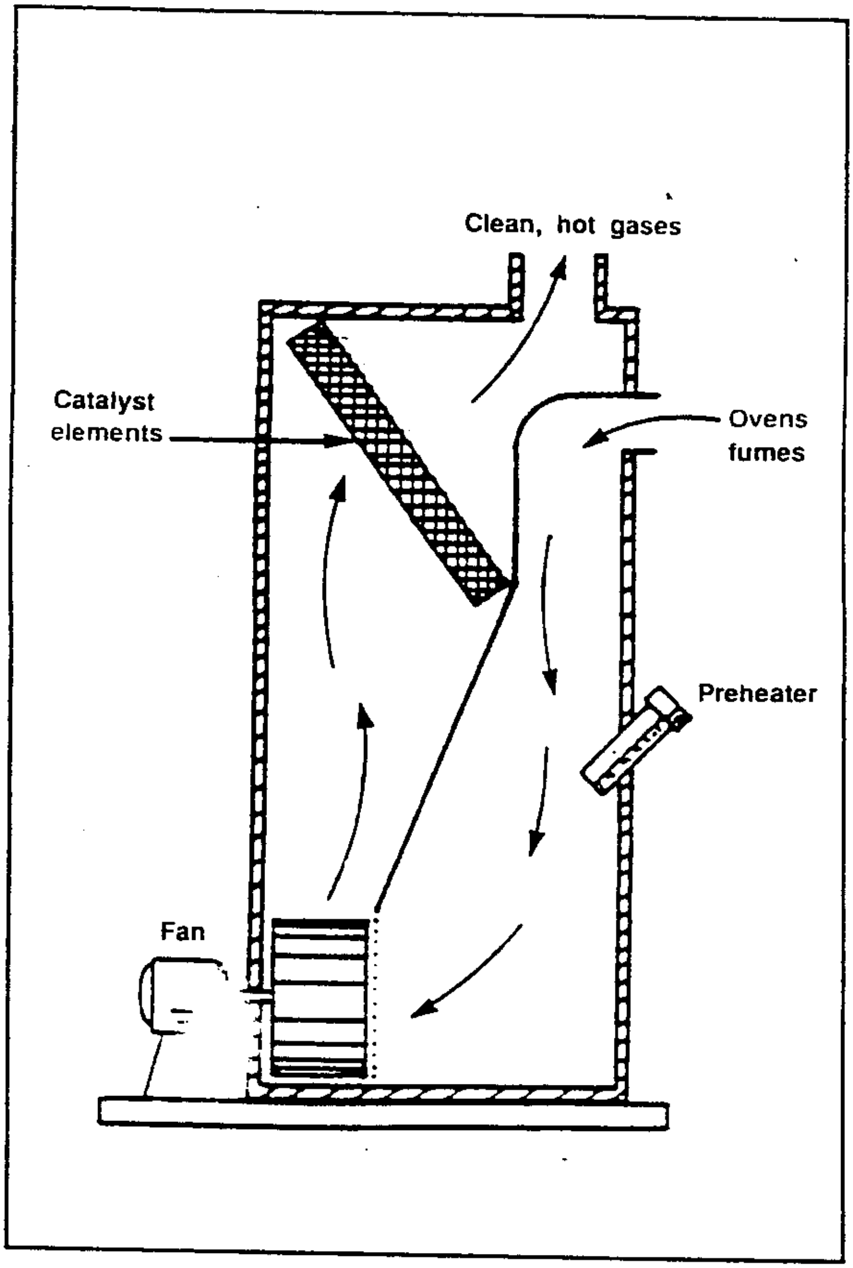

Figure 9-3. Catalytic Incinerator

The temperatures required for high-efficiency catalytic oxidation depend on the type of catalyst, the incinerator design, and the type of organic compound. Some typical operating temperatures for common compounds are provided in Table 9-2.

Table 9-2. Typical Operating Temperatures For 90 Percent Conversion In Catalytic Incinerators

Compound	Operating Temperature (°C)
Acetylene	200
Propylene	260
Ethylene	290
n-Heptane	300
Benzene	300
Toluene	300
Xylene	300
Ethanol	315
Methyl ethyl ketone	370
Methyl isobutyl ketone	370
Propane	410
Ethyl acetone	415
Ethane	430
Cyclopropane	455
Methane	490

What Problems Commonly Arise With Catalytic Incinerators?

Catalytic incinerators are vulnerable to a number of operating problems including catalyst thermal aging, catalyst thermal volatilization, catalyst attrition, catalyst masking, and catalyst poisoning by non-VOC contaminants. Each of these problems is briefly discussed below.

Catalytic incinerators can experience problems with catalyst aging, volatilization, attrition, masking, and poisoning.

Thermal aging is the inevitable result of gradual recrystallization of the noble metal materials because of their exposure to hot combustion products. The catalyst simply becomes less effective in promoting VOC-compound oxidation. All noble metal catalysts must eventually be replaced with fresh catalysts, typically after 3 to 5 years of operation.

Catalysts typically need to be replaced every 3 to 5 years.

Thermal volatilization is the sudden vaporization of the catalyst compound from the support matrix that makes up the catalyst bed. The temperature excursions that cause catalyst losses are often caused by an

If significant volatilization occurs, the catalyst bed must be replaced.

increase in the VOC concentrations in the waste gas stream. The catalyst bed must be replaced if signifi‿ant volatilization has occurred.

Catalyst attrition can result from cleaning procedures. Water-soluble material on the catalyst's surface can be removed by simply washing with a detergent solution. Non-water-soluble materials can sometimes be removed by washing with solvent and/or by physically scrubbing the catalytic materials. However, such cleaning procedures wear away the catalytic materials.

Masking prevents contact between the organic compounds and the surface of the catalyst.

Masking inhibits catalytic activity by preventing contact between the vapor-phase organic compounds and the surface of the catalytic material. This problem can result from deposition of particulate material on the catalyst bed or from soot formation in the preheater burner. Masking causes no permanent damage to the catalyst unless the cleaning process results in physical attrition of the catalyst from the surface of the substrate.

Poisoning involves an irreversible chemical reaction between contaminants and catalysts.

Poisoning of the catalyst involves irreversible chemical reactions between gas stream contaminants and the catalyst material. Poisoning can significantly reduce VOC oxidation efficiency because the catalyst is no longer effective in the oxidation reactions. Therefore, the catalyst bed must be replaced if a significant fraction of the catalyst has been affected.

Table 9-3 is a partial list of common materials that can cause catalyst poisoning and masking. It should be noted that the severity of the

Table 9-3. Catalyst Poisons And Masking Materials

Type Of Poison/Masking Material	Effect
Fast-acting poisons Phosphorous, bismuth, lead, arsenic, antimony, mercury	Irreversible reduction of catalyst activity at a rate dependent on concentration and temperature.
Slow-acting poisons Iron, tin, silicon	Irreversible reduction of catalyst activity. Higher concentrations than those of fast-acting catalyst inhibitors can be tolerated.
Reversible inhibitors Sulfur, halogens, zinc	Reversible surface coating of catalyst active area at a rate dependent on concentration and temperature.
Surface maskers Organic solids	Reversible surface coating of catalyst active area. Removed by increasing catalyst temperature.
Surface eroders and maskers Carbon particles Silicon particles	Surface coating of catalyst active area. Also, erosion of catalyst surface at a rate dependent on particle size, grain loading, and gas stream velocity.

poisoning or masking depends on the specific type of catalyst, the gas stream temperatures, and the concentration of the catalyst inhibitor.

One indication of catalyst inhibition is a lower-than-normal gas temperature increase across the catalyst bed. Because the oxidation reactions occurring on the catalyst bed are exothermic (i.e., heat liberating), the temperature increase should be significant if the catalyst is in good condition. Unfortunately, variations in the inlet VOC concentrations can also affect the rise of gas temperature across the bed. Low VOC concentrations result in a relatively small temperature increase.

Lower-than-normal gas temperature increases across the catalyst bed might indicate catalyst inhibition. Also, low inlet-VOC concentrations cause a similar effect.

Typical Emission Points

The uncontrolled emissions from an incinerator are generally vented through a stack. Emissions can also occur from a bypass stack that is used in the event of a malfunction. Emissions can result from corrosion of the incinerator and associated ductwork.

Typical Inspection Areas

The major inspection areas for the system include:

- Stack or vent exit.
- Bypass stack.
- Physical condition of the unit (corrosion).
- Internal physical condition (inspect only when out of service).
- Static pressure gauge.
- Hood used to collect VOCs for incineration.

Summary

Thermal and catalytic incinerators are used to control gaseous and combustible particulate emissions from curing ovens, dryers, and other sources. The catalytic incinerators use catalysts to promote combustion; therefore, they operate at lower temperatures than do thermal incinerators.

The function of incinerators is to completely oxidize the organic gases and combustible particulate matter. Organic materials in the exhaust gas streams react with O_2 in the air to form nontoxic substances, such as CO_2 and water vapor.

To achieve complete combustion, the pollutants must be heated to the proper temperature, mixed with sufficient O_2, and retained in the chamber long enough to allow combustion.

Review Exercises

1. True or false? The VOC compounds are oxidized within the burner flame itself in thermal incinerators but not in catalytic incinerators.

2. When complete combustion of a gas containing only organic compounds occurs, __________ and __________ are the products formed.

   a. Smoke; heat
   b. CO; HCl
   c. Water vapor; CO_2
   d. CO; CO_2

3. Which of the following is <u>not</u> critical to achieving complete combustion?

   a. Retention time
   b. Thermal barrier
   c. Temperature
   d. Turbulence

4. To ensure efficient combustion, the waste gas must be heated to at least its:

   a. Auto-ignition temperature
   b. Boiling point
   c. Vapor pressure
   d. Critical temperature

5. The amount of excess air used in an incinerator is kept low because:

   a. Heating the excess air to the operating temperature of the incinerator requires additional fuel.
   b. Heating the excess air increases operating costs.
   c. Excess air can reduce VOC removal efficiency.
   d. All of the above.

6. True or false? Residence time is determined by the size of the combustion chamber and the gas flow rate through the chamber.

7. The VOC concentration in the inlet gas stream is typically limited to ____ percent of the LEL.

   a. 10
   b. 15
   c. 20
   d. 25

Symptoms of poor thermal incinerator burner performance include:

   a. Generation of blue smoke.
   b. Higher-than-normal outlet temperatures.
   c. Lower-than-normal outlet temperatures.
   d. Lower-than-normal VOC outlet concentrations.

9. True or false? Variable VOC concentrations and gas flow rates can lead to operating problems in both thermal and catalytic incinerators.

10. In a catalytic incinerator, does oxidation occur at a higher or lower temperature than in a thermal incinerator?

11. True or false? If a preheater unit is not operating at the time of the inspection, the catalytic incinerator cannot be operating correctly.

12. Noble metal catalysts are usually replaced every:

    a. 6 months
    b. 1 to 2 years
    c. 3 to 5 years
    d. 10 years

Answers

1. False. The burner flame provides the turbulent mixing and temperature needed for combustion.
2. c. water vapor; CO_2
3. b. Thermal barrier
4. a. Auto-ignition temperature
5. d. All of the above.
6. True
7. d. 25
8. c. Lower-than-normal outlet temperatures.
9. True
10. Lower
11. False. The preheater might just not be needed at that time.
12. c. 3 to 5 years

Quiz 2: Covering Lessons 5-9

This is the second self-graded quiz, covering Lesson 5 through Lesson 9, with eight items from each lesson. In addition to providing feedback on your mastery of the material, it gives you practice at taking a test in the final exam format. There is no answer sheet; just circle your responses on this quiz. After you have completed the quiz, use the answer key for Quiz 2 in the back of the book to check your responses.

1. True or false? The alkaline feed requirements are much higher for spray dryer absorbers than for the other two categories of dry scrubbers.

2. Which of the following dry scrubbing systems appears to remove pollutants very efficiently?

   a. Spray dryer absorption.
   b. Dry injection adsorption.
   c. Combination spray dryer absorption/dry injection adsorption.
   d. All of the above.
   e. a and c only.

3. True or false? Two differences among dry scrubbing systems are the physical form of the alkaline reagent and the design of the vessel used for contact.

4. The atomizers that generate very small droplets in a broad spray pattern are:

   a. Rotary atomizers
   b. Nozzle-type atomizers

5. True or false? In a spray dryer absorber, the unit might have to be shut down if all slurry droplets do not evaporate before reaching the side walls of the absorber vessel or before leaving the absorber with the gas stream.

6. The pollutant removal efficiency of a dry injection adsorber depends on the:

   a. Reagent particle size.
   b. Adequacy of dust cake formation.
   c. Quantity of reagent injected.
   d. All of the above.
   e. a and c only.

7. True or false? One problem with spray dryer absorbers is that the slurry feed line to the atomizer can become plugged.

8. True or false? Spray dry absorbers usually operate with a baghouse. Within the absorber vessel of spray dry absorbers, the reagent is fluidized and mixed with the gas stream.

9. Wet scrubbers are pollution control devices that use:

   a. Absorption and adsorption to remove acidic gaseous pollutants from a gas stream.
   b. Liquid to remove particles or gases from exhaust streams.
   c. Gravity settling, inertia, and dry impaction processes to collect pollutants.
   d. Adsorption to remove organic vapors from an effluent gas stream.

10. A simple type of wet scrubber that has limited ability to remove small particles is the:

    a. Spray tower scrubber
    b. Moving bed scrubber
    c. Venturi scrubber
    d. Tray-type scrubber

11. The most important function of packing materials in wet scrubbers is to:

    a. Increase the strength of the scrubber walls, thus reducing pressure on the system.
    b. Provide high liquid flow rates.
    c. Maximize the surface area available for absorption of gases and vapors.
    d. Control temperature fluctuations.

12. True or false? The most important operating variables for packed bed scrubbers are gas velocity and degree of channeling.

13. Moving bed scrubbers are particularly suited for:

    a. Gas streams with low loadings of solids.
    b. Small particles.
    c. Gas streams with high loadings of solids or with sticky particles.
    d. a and b.

14. Key operating parameters of __________ scrubbers include liquor flow rate, degree of channeling, static pressure drop, suspended-solids content of the liquor, and surface tension of the liquor.

    a. Tray-type
    b. Moving bed
    c. Venturi
    d. Mechanically aided

15. Key operating parameters of __________ scrubbers include liquor flow rate and fan rotation speed.

    a. Tray-type
    b. Moving bed
    c. Venturi
    d. Mechanically aided

16. True or false? One or two wear-resistant vanes are used in mechanically aided scrubbers so gas velocity can be varied.

17. The particulate matter control devices that use gravity settling, inertia, and dry impaction processes to collect pollutants are:

    a. Dry scrubbers
    b. Wet scrubbers
    c. Mechanical collectors
    d. Multibed-type carbon bed adsorbers

18. The primary operating parameter for evaluating mechanical collectors is:

    a. Liquid-to-gas ratio
    b. Static pressure drop
    c. Degree of channeling
    d. Particle size distribution

19. Particles are collected in a mechanical collector cyclone because of:

    a. Their electrostatic attraction to the walls.
    b. Sieving action.
    c. Their inertia, which causes them to break out of the gas stream and hit the wall of the cyclone.
    d. A blast of air, which sends them against the walls of a filter.

20. Particle collection efficiency in a mechanical collector cyclone depends upon:

    a. Inlet gas velocity
    b. Cyclone dimensions
    c. Particle size
    d. Dust concentration
    e. All of the above
    f. a and b only
    g. a, b, and c only

21. Which mechanical collector is most effective in removing relatively large particles?

    a. Large-diameter cyclone
    b. Small-diameter cyclone
    c. Multicyclone

22. True or false? Multicyclone collectors contain a series of small cyclones; therefore, they are more efficient than are large-diameter cyclones in removing small particles.

23. True or false? Because of the state-of-the-art construction of most mechanical collectors, the physical condition of the cyclone body has little, if any, effect on collection efficiency.

24. True or false? In cyclone collectors, the collection efficiency tends to increase when the inlet gas velocity, particle size, and dust concentration increase.

25. Particulate control devices that remove organic vapors from an effluent gas stream and then remove pollutant molecules from the gas stream are:

    a. Dry scrubbers
    b. Wet scrubbers
    c. Mechanical collectors
    d. Multibed-type carbon bed adsorbers

26. True or false? In air pollution control, adsorption is not a final control process because the adsorbent material must be disposed of, replaced, or regenerated.

27. The equilibrium capacity of the carbon bed in a multibed-type carbon bed adsorber is determined by:

    a. Two variables in the carbon core—the heel and the working capacity.
    b. Desorption time and temperature.
    c. Breakthrough point and working capacity.
    d. Adsorption rate and temperature.

28. During vapor adsorption, when the carbon starts to near saturation and traces of vapor begin to appear in the exit gas stream, this is called:

    a. Regeneration
    b. The breakthrough point
    c. Equilibrium capacity
    d. Working capacity

29. During vapor adsorption, the desorption of collected organic pollutants from the carbon bed is called:

    a. Regeneration
    b. The breakthrough point
    c. Equilibrium capacity
    d. Working capacity

30. True or false? Organic pollutants are typically desorbed by passing cooled gases through the bed in the same direction as the flow of gases during adsorption.

31. True or false? If steam is used for regeneration, it is condensed with the desorbed solvents, and the collected liquid is either decanted or distilled to separate the water from the recovered solvent.

32. True or false? In carbon bed adsorbers, the working capacity is the size of the region in the carbon pore that is available to adsorb the pollutant.

33. ____________ are commonly used when it is not economical to recover the organic vapors or when compliance cannot be achieved by using low solvent material.

a. Mechanical collectors
b. Incinerators
c. Multibed-type carbon adsorbers
d. Dry scrubbers

34. It is important for incinerators to achieve complete combustion because incomplete combustion can:

a. Damage the heat recovery equipment.
b. Result in inefficient operation, increasing operational cost.
c. Form new, potentially more toxic compounds.
d. All of the above.
e. a and b only.

35. Which of the following is/are <u>not</u> critical to achieving complete combustion in an incinerator?

a. Turbulence
b. Residence time
c. Masking
d. Temperature
e. a and c

36. Most operation and maintenance problems of thermal incinerators are associated with the:

a. Refractory-lined combustion chamber
b. Burner
c. Stack
d. Electrical system

37. True or false? The oxidation reaction proceeds at a faster rate and at a lower temperature in a thermal incinerator than in a catalytic incinerator.

38. True or false? Preheater burners are used in thermal incinerators to achieve the required operating temperature.

39. In catalytic incinerators, thermal aging refers to:

a. Sudden vaporization of the catalytic compound from the support matrix that makes up the catalyst bed.
b. Inhibition of catalyst activity by preventing contact between the vapor-phase organic compounds and the surface of the catalyst material.
c. Irreversible chemical reactions between gas stream contaminants and the catalyst material.
d. Gradual recrystallization of the noble metal materials because of their exposure to hot combustion products.

40. True or false? In catalytic incinerators, a low temperature increase might be the result of catalyst inhibition or of a short-term decrease in the VOC concentration.