# Principles Of Control Technology

## Introduction

Industrial sources generally have two basic reasons for cleaning up the waste gases that they produce—profits and protection. Profits can be gained if hot gases from a process can be used for heating or for generating power; however, contaminants or impurities in the gas stream must be removed if the waste gas stream is to be used effectively. In addition, industry must protect its workers, the surrounding population, and the environment from waste gases that contain toxic or hazardous substances.

### *How Are Gas Streams Cleaned?*

*Basic scientific processes underlie all gas-stream cleaning.*

Polluted gas streams are cleaned in much the same way that nature cleans the atmosphere. However, gas streams that are subject to environmental regulations are treated before they are released into the ambient environment. As gases flow through ducts, they are subjected to control devices. These control devices either concentrate and remove pollutants, or chemically alter them so that they are no longer environmental hazards. The cleaned gas can then be processed further, or it can be emitted directly into the atmosphere through stacks or vents. In both cases, it is desirable that the cleaned gas stream conform to standard ambient air conditions: excess moisture should be removed; the level of contaminants should be as low and as consistent with applicable regulatory requirements as possible; and the temperature should be appropriate for the intended use of the gas stream.

*Gas removal mechanisms include:*
- *Absorption*
- *Adsorption*
- *Combustion*
- *Condensation*

*Particle removal mechanisms include separation by:*
- *Gravity*
- *Centrifugal force*
- *Impaction*
- *Diffusion*
- *Electrostatic precipitation*

The methods selected for contaminant control or removal depend on the nature of the material to be removed. If the material is a gas, the mechanisms generally used are **absorption, adsorption, combustion,** and **condensation**. If the material is a particle, the removal mechanisms involve some type of applied force, which might include **gravity separation, centrifugal separation, inertial impaction, diffusion**, or **electrostatic precipitation.**

## Collection Mechanisms For Gaseous Pollutants

As noted previously, the major collection mechanisms for gaseous pollutants are absorption, adsorption, combustion, and condensation. The applicability of each technique depends on the physical and chemical properties of the gaseous pollutant and of the gas stream.

## Absorption

*In absorption, a gas is dissolved in a liquid.*

Absorption is a process in which a gas is dissolved in a liquid. A contaminant in a gas stream makes contact with a liquid, and the contaminant diffuses from the gas phase into the liquid phase (i.e., the gas flows from an area of high concentration in the gas stream to an area of low concentration in the liquid). The rate at which the gas is absorbed depends on the diffusion rates of the liquid and gas phases; the solubility of the contaminant (the amount of a substance that can be dissolved in a given amount of solvent under specified conditions); the liquid-gas contact area; and the amount of mixing between the liquid and gas phases—called **turbulence.**

Gas absorbers (called **wet scrubbers**) are designed to provide sufficient mixing of the gas and liquid phases. This mixing improves absorption and the overall effectiveness of the contaminant collection device.

## Adsorption

*In adsorption, gas adheres to the surface of a solid.*

Adsorption is a process that involves removing gaseous contaminants by causing them to adhere to the surface of solid bodies with which they are in contact. Adsorption can be either physical or chemical. In physical adsorption, a gas molecule adheres to the surface of the solid because of an imbalance of natural forces. Physical adsorption is readily reversible; that is, the adsorbent can be easily **desorbed.** In chemical adsorption, once the gas molecules adhere to the surface, they chemically react with the substance. Thus, chemical adsorption is not easily reversible; it is difficult to desorb the adsorbent.

*Activated carbon is a frequently used adsorbent.*

All solids physically adsorb gases to some extent. Certain solids have a high attraction for specific gases and have large surface areas that enhance adsorption. One of the most-used adsorbents in air pollution control is **activated carbon.**

Adsorption allows easy removal of very small quantities of gas from the gas stream. The gas is not destroyed as it is removed; it is stored on the adsorbent surface until it is removed by desorption.

## Combustion

*Combustion is rapid, high-temperature, gas-phase oxidation.*

Combustion is rapid, high-temperature, gas-phase oxidation. In this process, the contaminant or gas is oxidized and converted to $CO_2$ and water vapor. Combustion is governed by **temperature, turbulence,** and **time**. For complete combustion to occur, each gas molecule must come into contact wit[illegible] at a [illegible]cient temperature and for a time adequate to oxidize the pollutant.

Combustion devices include **flares, thermal incinerators,** and **catalytic incinerators.** Flares are direct-combustion devices. Thermal incinerators are devices in which the gas contaminant passes around or through a burner and into a **refractory-line residence chamber** where oxidation takes place. In catalytic incineration, the contaminated gas stream is heated and is passed through a **catalyst bed** that promotes the oxidation reaction at lower temperatures than would be necessary were the catalyst not present.

## Condensation

Condensation is a process by which volatile contaminant gases are removed from a gas stream by adjusting the gas stream temperature until the contaminant gas changes into a liquid. Condensation requires low temperatures to liquefy most contaminant gases. Noncondensable gases in the gas stream pass through the condensation process unaffected.

*In condensation, gas is cooled and becomes a liquid.*

Condensation devices (**condensers**) are often used in combination with other control devices and are located upstream from (before) an incinerator, absorber, or adsorber. The use of condensers helps reduce the cost and size of the primary control device by reducing the volume of gas to be treated. Condensers also remove water vapor from gas streams that have a high moisture content (moisture can affect the performance of the primary device).

## Collection Mechanisms For Particulate Pollutants

As noted previously, particulate pollutants are collected using applied force, including gravity, centrifugal force, impaction, diffusion, and electrostatic precipitation.

<u>Gravity</u>. The simplest applied force is gravity. Large particles move slowly through the gas stream, are overcome by gravity, and are collected at the bottom of the control device. Gravity is responsible for particle collection in the **settling chamber**—the simplest particulate control device.

<u>Centrifugal Force</u>. Centrifugal force is another collection mechanism for particulate pollutants. With centrifugal force, the shape or curvature of the collector causes the gas stream to rotate in a spiral motion. Larger particles move toward the outer wall by their **momentum**. The particles lose their kinetic energy as they strike the wall of the collector and are separated from the gas stream. The particles are then overcome by gravitational forces and collect at the bottom of the control device.

*With centrifugal force, the shape of the collector causes the gas stream to rotate in a spiral motion.*

<u>Impaction</u>. Impaction, another collection mechanism, involves direct contact between a particle and an object. Figure 2-1 illustrates this process in a filter. The particle is too large to follow the gas stream lines around the filter fiber, so it strikes the fiber. **Direct interception** is a special case of impaction (Figure 2-2). The center of the particle follows the stream lines around the fiber, but collision occurs because the distance between the particle's center and the collection surface is less than the particle's radius.

*Impaction involves direct contact between a particle and an object.*

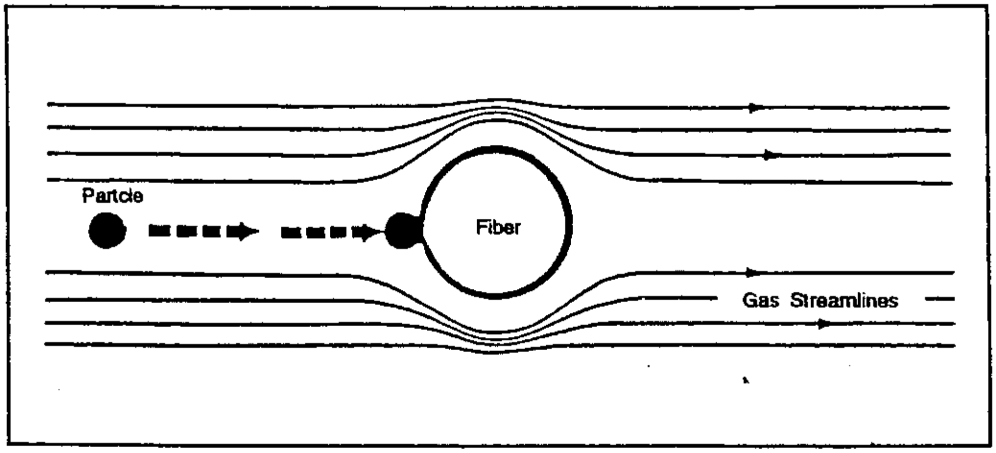


**Figure 2-1. Impaction**

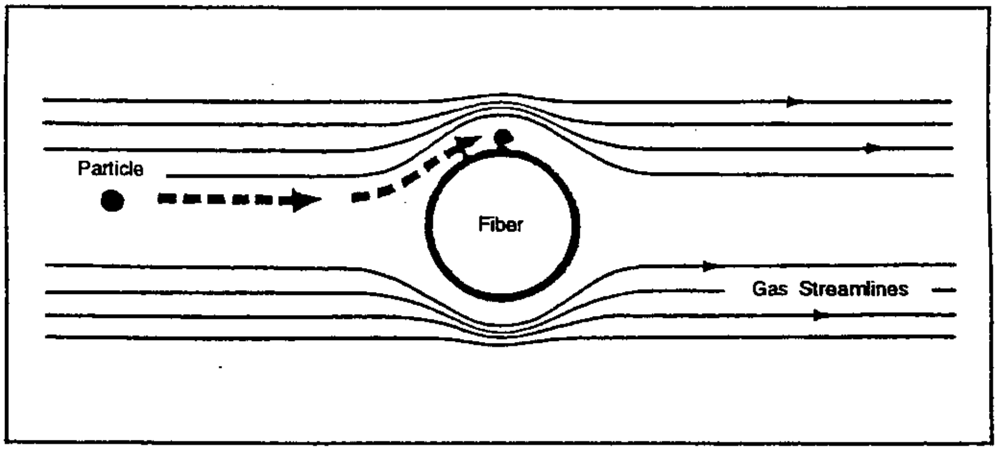


**Figure 2-2. Direct Interception**

*Diffusion relies on erratic particle movement.*

Diffusion. Diffusion is another collection mechanism for particulate pollutants. Small pollutant particles are continually and regularly bombarded gas molecules; this causes the particles to move in an erratic, zigzag mann The particles move through the gas stream until they strike an object, such as a fiber in a fabric filter system (Figure 2-3).

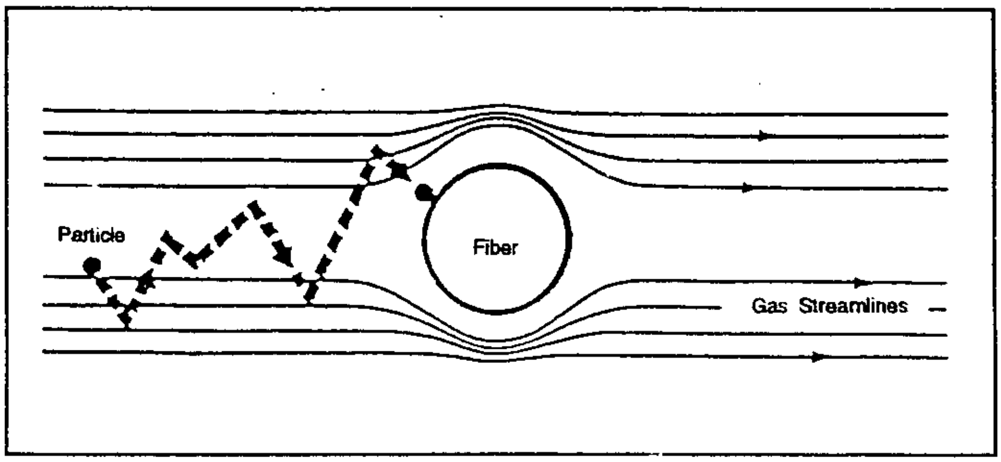


**Figure 2-3. Diffusion**

Electrostatic Precipitation. This primary particle collection mechanism uses electrostatic forces. Many particles are naturally charged and others can be charged by being subjected to a strong electrical field. The charged particles migrate to an oppositely charged collection surface where they become attached (Figure 2-4).

*In electrostatic precipitation, charged particles migrate to an oppositely charged collection surface.*

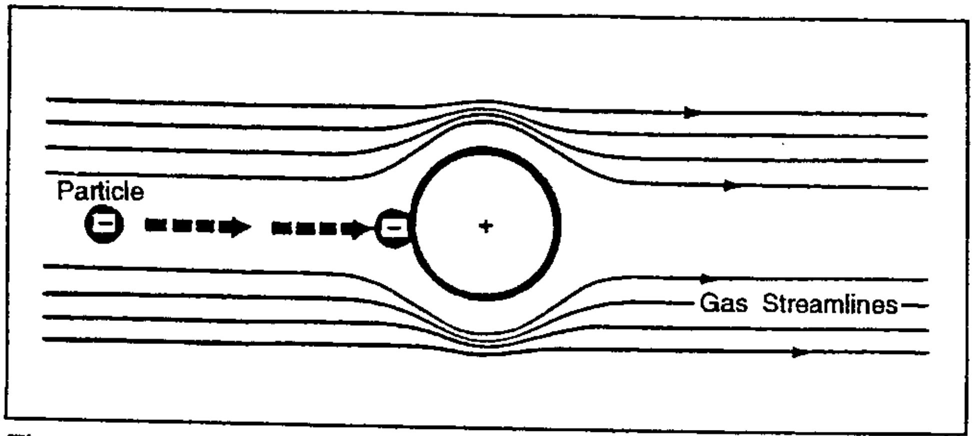


**Figure 2-4. Electrostatic Precipitation**

# Factors Affecting Control Device Selection

There are many factors to consider when selecting a control device to reduce emissions. These factors include the contaminant's **concentration, characteristics,** and **chemical** and **physical properties.**

*Selection factors include the contaminant's:*
- *Concentration*
- *Characteristics*
- *Chemical and physical properties*

Concentration. The first factor to be considered in selecting a control device is the concentration of the contaminant in the gas stream. Pollutant concentration is typically expressed in terms of parts per million (ppm), pounds per cubic foot ($lb/ft^3$), grains per cubic foot ($gr/ft^3$), and grams per cubic meter ($g/m^3$). Some control devices cannot handle great fluctuations in the concentration of incoming gas because the design of the device is closely related to that concentration. In other cases, such fluctuations in incoming concentration are not a problem because the major design parameters are more related to the concentration of the outgoing gas.

*Design parameters determine whether a device can handle fluctuations in concentration.*

Characteristics. The second factor in selecting a control device is the contaminant's characteristics, including particle size. Particle size is usually expressed by the **aerodynamic diameter,** which is measured in micrometers (µm). The aerodynamic diameter describes how the particle moves in a gas stream. The larger particles (> 60 µm) can be collected in simple devices, such as settling or **baffle chambers**. Particles greater than 10 µm can be collected in cyclones or multi-cyclones. Smaller particles (< 5 µm) must be collected in more sophisticated devices, such as scrubbers, baghouses, or ESPs. Particle size, then, plays a large role in the collection efficiency of a specific control device.

*Particle size is an important factor in control device collection.*

*A contaminant's electrical properties can be both a hindrance and an aid.*

Properties. The third factor in control device selection is the contaminant's chemical and physical properties. The contaminant's electrical properties can be both a hindrance and an aid in its collection. Static electricity can create a buildup of solids in both inertial and baghouse collectors. Layers of dust particles, called cakes, can form on the bag filters as a result of the static electric forces and can be difficult to dislodge. In an ESP, however, particulate matter collection depends on the ability of the precipitator to charge the particles. Particles passing through an electric field are charged and, consequently, migrate to an oppositely charged collection plate. Although there are many factors that govern particle charging, the primary factor governing adequate particle collection is the particle's **resistivity** (the resistance of the collected dust layer to the flow of electric current).

### *What Restrictions Apply When The Particles Are Potentially Explosive?*

*ESPs cannot be used with explosive particles.*

If the particles in the gas stream are potentially explosive, ESPs cannot be used; the generated electric charge could cause the particles to ignite. Fabric filters might be used, but only if there are no static electric effects in the baghouse. For explosive particles, the logical choice of a control device would depend on the physical and chemical properties that cause the dust to be explosive.

### *What Is Hygroscopicity?*

*Hygroscopicity is the tendency of materials to absorb water.*

**Hygroscopicity** is the tendency of materials to absorb water. It is a physical characteristic of some particles that causes changes in the particles' crystal structure as water is added. Some particles, such as sodium sulfate ($Na_2SO_4$), can absorb up to 12 moles of water per mole of anhydrous salt in high-humidity conditions. Other particles, from processes such as alfalfa dehydration, alfalfa pelleting, and cotton ginning, are hygroscopic to varying degrees.

### *How Does Hygroscopicity Affect Certain Control Devices?*

The hygroscopic nature of the particle affects the performance of mechanical collectors by causing dust deposits to build up on the collectors' internal surfaces. This can cause internal plugging or unpredictable dust cake discharges into collection hoppers at various times. Hygroscopic particles also affect cleaning mechanisms in a baghouse by forming difficult-to-remove cakes on the bags.

### *How Do Toxic Pollutants Affect Control Device Selection?*

*Contaminant toxicity influences the location of the control device and air movement system.*

Contaminant toxicity is another property that affects control device selection. It influences the location of the control device and the location of the air movement system (**fan**). Highly toxic materials require the use of a negative pressure system so that leaks will be contained within the collector. A positive pressure system could cause fugitive emissions, thereby creating an occupational health and safety problem. In a negative pressure system, the fan is located downstream of (after) the air pollution control device. The volume of gas might increase slightly if air leaks into the collector, but little or no contaminant leakage from the air movement and control system should occur.

# Factors Affecting Control Device Efficiency

### *How Does Gas-Stream Temperature Affect Control Device Efficiency?*

*Gas-stream temperature is an important factor in removing contaminants.*

Gas-stream temperature is an important factor in the ability of the control device to effectively remove contaminants. The size and cost of the unit needed to treat a gas stream depend on the temperature of that gas stream. The volume of gas to be cleaned is larger at higher gas temperatures than it is at lower gas temperatures. Reducing the temperature reduces the volume of exhaust gas; however, reducing the temperature could create some additional problems. The gas-stream temperature must be maintained above the dew point of the gas to prevent water and acid from condensing in the collector. Water and acid mists could cause corrosion (or even complete deterioration) of the structural material of the collector.

High gas-stream temperatures can also cause failure of fabric filtration system components. At exhaust gas temperatures greater than 300 °C, most fabric materials will deteriorate. Gas temperature can also affect particle resistivity. Changing the temperature of the exhaust stream in an ESP can also change the resistivity of the particles, and thus the collection efficiency of the unit.

### *How Does Gas Velocity Affect Control Device Efficiency?*

*Large changes in flow rate will adversely affect the control efficiency.*

Gas velocity (the rate at which the gas stream flows through the control device) is also an important factor in control device efficiency. Velocity is usually expressed in feet per second (ft/s) or meters per second (m/s). Some control devices are designed to operate most efficiently at specific velocities. Large changes in the flow rate will adversely affect the control efficiency. If the gas velocity is too great, the gas stream does not remain in the control device long enough for the contaminants to be removed. Conversely, too low a velocity might not allow the control device to separate the contaminant from the gas stream (especially in a mechanical collector).

### *What About Pressure Drop?*

*Pressure drop is the amount of pressure lost between the inlet and outlet sections of the control device.*

Pressure drop is another important factor in control device efficiency. It is the amount of pressure lost between the inlet and outlet sections of the control device (usually expressed in millimeters of mercury [mm Hg] or inches of water [in. $H_2O$]). This reduction in pressure slows down the gas stream. Therefore, collectors with large pressure drops would require larger fans (and greater power requirements) to either push or pull the exhaust gas through the system. An increase in pressure drop means that there is a larger pressure loss in the system. Some control devices, such as venturi scrubbers, are designed to operate at high pressure drops (as great as 60 in. $H_2O$; 14.9 kilopascals [kPa]). Electrostatic precipitators, however, are designed to operate at much lower pressure drops (usually less than 10 in. $H_2O$; 2.49 kPa) to obtain collection efficiencies that are similar to those obtained with venturi scrubbers.

## Summary

Controlling waste gases can produce profits and can protect the population and the environment. Profits are gained when gases from a removal process can be used for heating or for generating power. The surrounding population, the environment, and the workers are protected because the ambient air contains fewer contaminants.

Removal mechanisms for pollutants in gases include absorption, adsorption, combustion, and condensation. Removal mechanisms for particulate pollutants involve using applied force, i.e., gravity, centrifugal force, impaction, diffusion, and electrostatic precipitation.

In selecting a control device, one must consider the contaminant's concentration, characteristics, chemical properties, and physical properties. Factors that affect control device efficiency include gas-stream temperature, gas velocity, and pressure drop.

# Review Exercises

1. The four mechanisms commonly used to remove gaseous pollutants are ______________, ______________, ______________, and ____________.

2. True or false? Absorption is the process that occurs when a gas is dissolved in a liquid.

3. True or false? The rate at which a gas is absorbed depends entirely on the solubility of the absorbent.

4. The two types of adsorption are ____________ and ____________.

5. True or false? Activated carbon is one of the most commonly used absorbents for air pollution control.

6. True or false? During adsorption, the contaminant is destroyed.

7. Combustion is governed by:

   a. Time
   b. Temperature
   c. Turbulence
   d. All of the above
   e. None of the above

8. True or false? Catalytic incinerators operate at higher temperatures than do other thermal incinerators.

9. True or false? Condensation devices are often used in combination with other control devices.

10. Particulate matter collection mechanisms include:

    a. Gravitational forces
    b. Centrifugal forces
    c. Impaction
    d. All of the above
    e. None of the above

11. True or false? Diffusion and electrostatic forces are two particulate matter collection mechanisms.

12. True or false? Pollutant concentration is one of the factors that influence control device selection.

13. True or false? Particle size is expressed in terms of $lb/ft^3$.

14. True or false? Venturi scrubbers generally operate at low pressure drops.

# Answers

1. absorption; adsorption; combustion; condensation
2. True
3. False. It depends only in part on the solubility; it also depends on diffusion rate, liquid-gas contact, and turbulence.
4. physical; chemical
5. False. Activated carbon is used as an <u>ad</u>sorbent.
6. False. During adsorption, the contaminant is not destroyed.
7. d. all of the above
8. False. Because of the catalytic reaction, catalytic incinerators can operate at lower temperatures.
9. True
10. d. all of the above
11. True
12. True
13. False. Particle size is expressed in terms of aerodynamic diameter, which is measured in micrometers.
14. False. Venturi scrubbers generally operate at high pressure drops.