



Air Pollution Technology Fact Sheet



1. *Name of Technology:* Cyclones

This type of technology is a part of the group of air pollution controls collectively referred to as “precleaners,” because they are oftentimes used to reduce the inlet loading of particulate matter (PM) to downstream collection devices by removing larger, abrasive particles. Cyclones are also referred to as cyclone collectors, cyclone separators, centrifugal separators, and inertial separators. In applications where many small cyclones are operating in parallel, the entire system is called a multiple tube cyclone, multicyclone, or multiclone.

2. *Type of Technology:*

Removal of PM by centrifugal and inertial forces, induced by forcing particulate-laden gas to change direction.

3. *Applicable Pollutants:*

Cyclones are used to control PM, and primarily PM greater than 10 micrometers (μm) in aerodynamic diameter. However, there are high efficiency cyclones designed to be effective for PM less than or equal to 10 μm and less than or equal to 2.5 μm in aerodynamic diameter (PM_{10} and $\text{PM}_{2.5}$). Although cyclones may be used to collect particles larger than 200 μm , gravity settling chambers or simple momentum separators are usually satisfactory and less subject to abrasion (Wark, 1981; Perry, 1984).

4. *Achievable Emission Limits/Reductions:*

The collection efficiency of cyclones varies as a function of particle size and cyclone design. Cyclone efficiency generally increases with (1) particle size and/or density, (2) inlet duct velocity, (3) cyclone body length, (4) number of gas revolutions in the cyclone, (5) ratio of cyclone body diameter to gas exit diameter, (6) dust loading, and (7) smoothness of the cyclone inner wall. Cyclone efficiency will decrease with increases in (1) gas viscosity, (2) body diameter, (3) gas exit diameter, (4) gas inlet duct area, and (5) gas density. A common factor contributing to decreased control efficiencies in cyclones is leakage of air into the dust outlet (EPA, 1998).

Control efficiency ranges for single cyclones are often based on three classifications of cyclone, i.e., conventional, high-efficiency, and high-throughput. The control efficiency range for conventional single cyclones is estimated to be 70 to 90 percent for PM, 30 to 90 percent for PM_{10} , and 0 to 40 percent for $\text{PM}_{2.5}$.

High efficiency single cyclones are designed to achieve higher control of smaller particles than conventional cyclones. According to Cooper (1994), high efficiency single cyclones can

remove 5 μm particles at up to 90 percent efficiency, with higher efficiencies achievable for larger particles. The control efficiency ranges for high efficiency single cyclones are 80 to 99 percent for PM, 60 to 95 percent for PM_{10} , and 20 to 70 percent for $\text{PM}_{2.5}$. Higher efficiency cyclones come with higher pressure drops, which require higher energy costs to move the waste gas through the cyclone. Cyclone design is generally driven by a specified pressure-drop limitation, rather than by meeting a specified control efficiency (Andriola, 1999; Perry, 1994).

According to Vatauvuk (1990), high throughput cyclones are only guaranteed to remove particles greater than 20 μm , although collection of smaller particles does occur to some extent. The control efficiency ranges for high-throughput cyclones are 80 to 99 percent for PM, 10 to 40 percent for PM_{10} , and 0 to 10 percent for $\text{PM}_{2.5}$. Multicyclones are reported to achieve from 80 to 95 percent collection efficiency for 5 μm particles (EPA, 1998).

5. *Applicable Source Type:* Point

6. *Typical Industrial Applications:*

Cyclones are designed for many applications. Cyclones themselves are generally not adequate to meet stringent air pollution regulations, but they serve an important purpose as precleaners for more expensive final control devices such as fabric filters or electrostatic precipitators (ESPs). In addition to use for pollution control work, cyclones are used in many process applications, for example, they are used for recovering and recycling food products and process materials such as catalysts (Cooper, 1994).

Cyclones are used extensively after spray drying operations in the food and chemical industries, and after crushing, grinding and calcining operations in the mineral and chemical industries to collect salable or useful material. In the ferrous and nonferrous metallurgical industries, cyclones are often used as a first stage in the control of PM emissions from sinter plants, roasters, kilns, and furnaces. PM from the fluid-cracking process are removed by cyclones to facilitate catalyst recycling. Fossil-fuel and wood-waste fired industrial and commercial fuel combustion units commonly use multiple cyclones (generally upstream of a wet scrubber, ESP, or fabric filter) which collect fine PM ($< 2.5 \mu\text{m}$) with greater efficiency than a single cyclone. In some cases, collected fly ash is reinjected into the combustion unit to improve PM control efficiency (AWMA, 1992; Avallone, 1996; STAPPA/ALAPCO, 1996; EPA, 1998).

7. *Emission Stream Characteristics:*

- a. *Air Flow:*** Typical gas flow rates for a single cyclone unit are 0.5 to 12 standard cubic meters per second (sm^3/sec) (1,060 to 25,400 standard cubic feet per minute (scfm)). Flows at the high end of this range and higher (up to approximately $50 \text{sm}^3/\text{sec}$ or 106,000 scfm) use multiple cyclones in parallel (Cooper, 1994). There are single cyclone units employed for specialized applications which have flow rates of up to approximately $30 \text{sm}^3/\text{sec}$ (63,500 scfm) and as low as $0.0005 \text{sm}^3/\text{sec}$ (1.1 scfm) (Wark, 1981; Andriola, 1999).

- b. Temperature:** Inlet gas temperatures are only limited by the materials of construction of the cyclone, and have been operated at temperatures as high as 540°C (1000°F) (Wark, 1981; Perry, 1994).
- c. Pollutant Loading:** Waste gas pollutant loadings typically range from 2.3 to 230 grams per standard cubic meter (g/sm^3) (1.0 to 100 grains per standard cubic foot (gr/scf)) (Wark, 1981). For specialized applications, loadings can be as high as 16,000 g/sm^3 (7,000 gr/scf), and as low as 1 g/sm^3 (0.44 gr/scf) (Avallone, 1996; Andriola, 1999).
- d. Other Considerations:** Cyclones perform more efficiently with higher pollutant loadings, provided that the device does not become choked. Higher pollutant loadings are generally associated with higher flow designs (Andriola, 1999).

8. **Emission Stream Pretreatment Requirements:**

No pretreatment is necessary for cyclones.

9. **Cost Information:**

The following are cost ranges (expressed in third quarter 1995 dollars) for a single conventional cyclone under typical operating conditions, developed using an EPA cost-estimating spreadsheet (EPA, 1996), and referenced to the volumetric flow rate of the waste stream treated. For purposes of calculating the example cost effectiveness, flow rates are assumed to be between 0.5 and 12 sm^3/sec (1,060 and 25,400 scfm), the PM inlet loading is assumed to be approximately 2.3 and 230 g/sm^3 (1.0 to 100 gr/scf) and the control efficiency is assumed to be 90 percent. The costs do not include costs for disposal or transport of collected material. Capital costs can be higher than in the ranges shown for applications which require expensive materials. As a rule, smaller units controlling a waste stream with a low PM concentration will be more expensive (per unit volumetric flow rate and per quantity of pollutant controlled) than a large unit controlling a waste stream with a high PM concentration.

- a. Capital Cost:** \$4,200 to \$5,100 per sm^3/sec (\$2.00 to \$2.40 per scfm)
- b. O & M Cost:** \$2,400 to \$27,800 per sm^3/sec (\$1.10 to \$13.10 per scfm), annually
- c. Annualized Cost:** \$2,800 to \$28,300 per sm^3/sec (\$1.30 to \$13.40 per scfm), annually
- d. Cost Effectiveness:** \$0.45 to \$460 per metric ton (\$0.41 to \$420 per short ton), annualized cost per ton per year of pollutant controlled

Flow rates higher than approximately 10 sm^3/sec (21,200 scfm), and up to approximately 50 sm^3/sec (106,000 scfm), usually employ multiple cyclones operating in parallel. Assuming the same range of pollutant loading and an efficiency of 90 percent, the following cost ranges (expressed in third quarter 1995 dollars) were developed for multiple cyclones, using an EPA cost-estimating spreadsheet (EPA, 1996), and referenced to the volumetric flow rate of the waste stream treated.

- a. **Capital Cost:** \$4,100 to \$5,000 per sm^3/sec (\$2.00 to \$2.40 per scfm)
- b. **O & M Cost:** \$1,600 to \$2,600 per sm^3/sec (\$0.75 to \$1.20 per scfm), annually
- c. **Annualized Cost:** \$2,000 to \$3,100 per sm^3/sec (\$0.90 to \$1.50 per scfm), annually
- d. **Cost Effectiveness:** \$0.32 to \$50 per metric ton (\$0.29 to \$46 per short ton), annualized cost per ton per year of pollutant controlled

10. Theory of Operation:

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

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

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

Pressure drop is an important parameter because it relates directly to operating costs and control efficiency. Higher control efficiencies for a given cyclone can be obtained by higher inlet velocities, but this also increases the pressure drop. In general, 18.3 meters per second (60 feet per second) is considered the best operating velocity. Common ranges of pressure drops for cyclones are 0.5 to 1 kilopascals (kPa) (2 to 4 in. H_2O) for low-efficiency units (high throughput), 1 to 1.5 kPa (4 to 6 in. H_2O) for medium-efficiency units (conventional), and 2 to 2.5 kPa (8 to 10 in. H_2O) for high-efficiency units (AWMA, 1992).

When high-efficiency (which requires small cyclone diameter) and large throughput are both desired, a number of cyclones can be operated in parallel. In a multiple tube cyclone, the housing contains a large number of tubes that have a common gas inlet and outlet in the chamber. The gas enters the tubes through axial inlet vanes which impart a circular motion (AWMA, 1992). Another high-efficiency unit, the wet cyclonic separator, uses a combination of centrifugal force and water spray to enhance control efficiency.

11. Advantages/Pros:

Advantages of cyclones include (AWMA, 1992; Cooper, 1994; and EPA, 1998):

1. Low capital cost;
2. No moving parts, therefore, few maintenance requirements and low operating costs;
3. Relatively low pressure drop (2 to 6 inches water column), compared to amount of PM removed;
4. Temperature and pressure limitations are only dependent on the materials of construction;
5. Dry collection and disposal; and
6. Relatively small space requirements.

12. Disadvantages/Cons:

Disadvantages of cyclones include (AWMA, 1992; Cooper, 1994; and EPA, 1998):

1. Relatively low PM collection efficiencies, particularly for PM less than 10 μm in size;
2. Unable to handle sticky or tacky materials; and
3. High efficiency units may experience high pressure drops.

13. Other Considerations:

Using multiple cyclones, either in parallel or in series, to treat a large volume of gas results in higher efficiencies, but at the cost of a significant increase in pressure drop. Higher pressure drops translate to higher energy usage and operating costs. Several designs should be considered to achieve the optimum combination of collection efficiency and pressure drop (Cooper, 1994).

14. References:

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