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Understanding Cyclone Dust Collectors

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...operating principles, specification needs, and costs

Cyclone separators are the simplest and least expensive dust collection devices for industrial air pollution control. Operation and maintenance are simple because they have no moving parts. This article discusses the most common cyclone separator design, the involute entry type with a counterflow, coaxial clean air outlet.

Operating Principle—Dust-laden air enters the cylindrical/conical body of the cyclone tangentially at the top and the flow assumes a vortex pattern as it travels helically downward, Fig. 1. Centrifugal force from the air's tangential velocity causes the heavier dust particles to move radically outward toward the cyclone's wall. When the particles reach the wall, friction and gravity force them to descend and discharge into a receiver. The cleaned air spirals upward and exits at the top of the cyclone.

Performance characteristics of a cyclone are determined by its proportions and size and by the properties and flow rates of the air and dust. Performance is described by pressure drop (energy consumption), fractional efficiency (weight percent collected of any particle size), and total efficiency (total collected weight percent).

A particle's radial velocity, determined by Stokes' law, is a function of the air's density and viscosity, the particle's density, the square of the particle's aerodynamic diameter, and the particle's acceleration. Acceleration is a function of the square of the volumetric air flow rate and the reciprocals of the square of the inlet area and of the cyclone's body diameter.

Because the flow patterns in the cyclone are three-dimensional, mathematical relationships describing performance characteristics are very complex. However, the application of established physical laws to empirical data derived from laboratory tests and field experience has resulted in accurate computer models for predicting cyclone performance. In turn, overall cyclone performance has improved, and the scope of applications for these units has broadened.

Cyclone Myths—To appreciate the range and type of air pollution problems that cyclone separators can economically and effectively solve, plant engineers must consider some misconceptions about the equipment.

Cyclones are suitable only for collecting particles down to about 5 to 10 microns. This statement is an oversimplification because it ignores two important variables, dust density and pressure drop. Some wood and paper dusts have particle densities of about 35 lb/cu ft and certain heavy metal compounds have densities of 700 lb/cu ft. Referring to Fig. 2, if the frac-

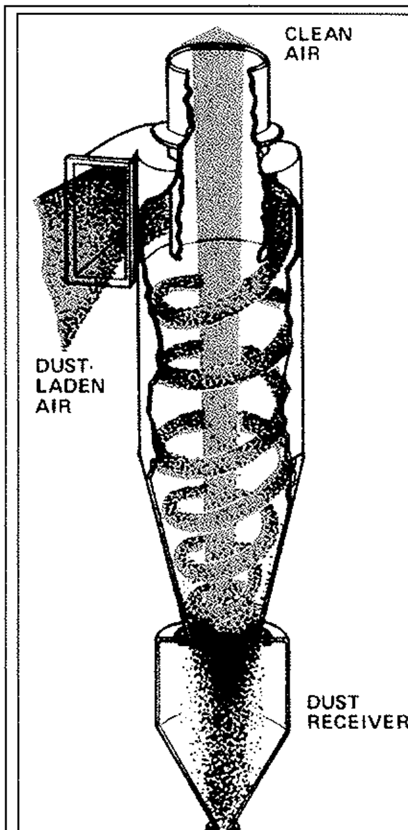

Fig. 1. Cyclone dust collector consists essentially of a cylindrical/conical shape with no moving parts. Dust particles are separated from the air stream by the centrifugal force created by the air's tangential velocity.

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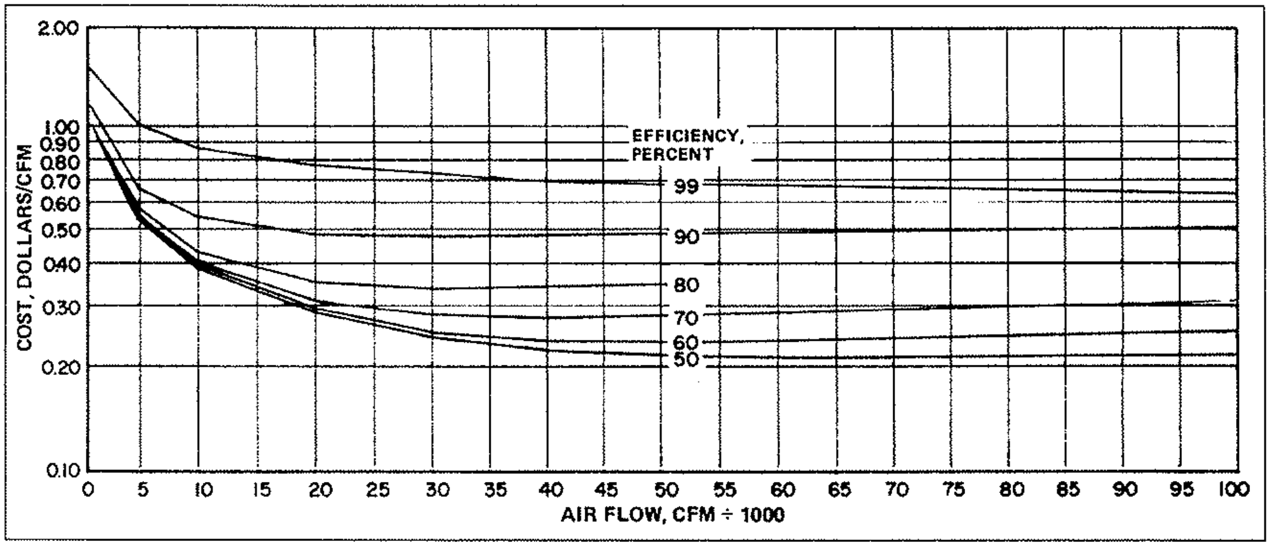

Fig. 3. Cyclone costs as functions of air flows at constant pressure drop and various efficiencies are shown by these curves. Pressure drop in all cases is 6.0 in. w.g. with air at standard temperature and pressure. Collection efficiencies listed for the cyclones are for 5 micron particles having 168.5 lb/cu ft density.

but would operate at only 44 percent of its inlet velocity and 18 percent of the pressure drop.

Cyclones perform better under positive pressure than under negative pressure. Cyclones must discharge into a properly proportioned, airtight space to perform as rated. Cyclone performance will not be affected by fan location if this criterion is adhered to. Therefore, performance is the same whether the unit is operating under negative or positive pressure.

However, the amount of space that the cyclone discharges into is important. In a high-performance cyclone, a very intense vortex exists at the dust discharge point. If dust is allowed to accumulate in this area it will re-entrain and discharge through the gas outlet. And if the dust receiver is not airtight, air may leak in and flow toward the dust discharge point, causing re-entrainment—even if the cyclone is operating under positive pressure.

Using airtight dust receivers sized to provide a dead air space with a diameter at least twice, and a height three to four times, the diameter of the dust discharge prevents these problems. No dust should be permitted to accumulate in this air space. Rotary-lock or double-dump feeder valves help ensure airtight receivers.

Specifying a Cyclone—Selecting the proper cyclone to provide a desired level of performance requires accurate and reliable operating data. In addition, information about construction materials, equipment features, and accessories is needed.

Operating conditions can be divided into gas and particulate conditions at the cyclone inlet. Gas data should include analysis (if gas is other than dry air, percent by weight or volume of each constituent should be specified), flow rate, temperature, and pressure.

Particulate data should include dust loading (weight per unit time or per unit volume of gas), particle density, size distribution, and an explanation of how density and size distribution data were determined.

A particle's behavior is affected by its mass, shape, geometric dimensions, and surface texture. Thus, to have any validity in predicting cyclone performance, the data must define the dust's aerodynamic properties. All information must be representative of the airborne particles entering the cyclone's inlet. Density and size distribution are best determined by measuring terminal or settling velocities in still air.

Performance requirements can be

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tional efficiency curve for cyclone 3 were revised to represent wood dust, the unit's efficiency on 2.0 micron particles would be 0.1 percent. However, the same cyclone at the same gas flow conditions would have a 91.1 percent efficiency in collecting 2.0 micron lead compound particles.

With a 2.9 in. w.g. pressure drop, the efficiency of cyclone 3 in collecting 2.0 micron particles of dust is 20.6 percent. If the gas flow rate is doubled or the cyclone's diameter is reduced from 6.5 to 4.6 ft, pressure drop increases to 11.6 in. and efficiency goes up to 60.9 percent. So, contrary to popular belief, cyclones can achieve high efficiencies in collecting particles down to 1.0 micron and (in some cases) below.

Cyclones typically operate at pressure drops in the 2 to 10 in. w.g. range. Cyclone pressure drop varies directly with gas density. In pollution control applications, air density normally is 0.075 lb/cu ft at standard temperature and pressure. However, in industrial processes, temperatures can range from 20 to 2000 F, and pressures from 20 in. Hg vacuum to 250 psig. Thus, air density can vary from 0.01 to 1.6 lb/cu ft, and, depending on gas conditions, cyclone pressure drop may vary by a factor of up to 160. Mixtures of air, water vapor, or other gases can further increase this range.

The relationship between cyclone efficiency and pressure drop is also disregarded by this myth. Typically, selecting a smaller cyclone within a given "family" results in higher efficiency. (A family of cyclones is defined as units that are geometrically proportional to each other, regardless of size.) Cyclone cost, plus the cost of related ductwork, support structures, and installation labor, is lower too. But motor and fan costs (in some cases) and energy consumption increase.

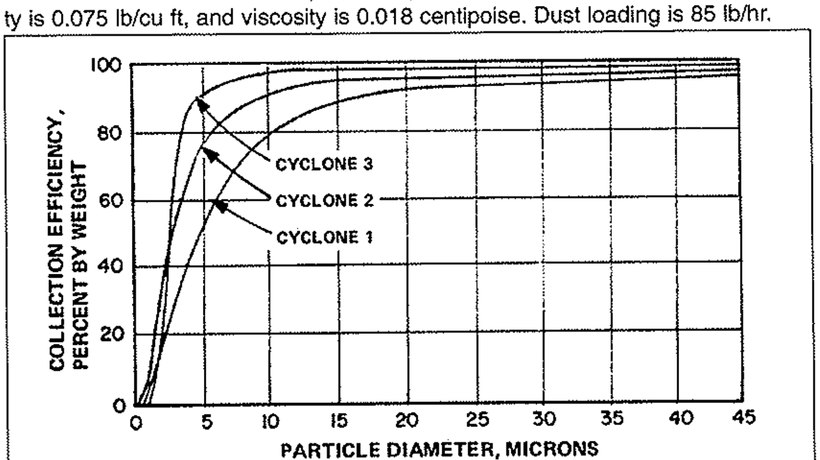
Probably the most important consideration overlooked in this myth is gas inlet velocity. Most literature assumes that air velocities range between 20 and 100 fps, with the velocity in the majority of industrial applications falling between 40 and 60 fps. However, laboratory tests and field applications have shown that inlet velocities can be as low as 10 fps and as high as or above 150 fps.

At low velocities, it is important that dust does not settle out and obstruct the cyclone inlet. The threat of abrasion and erosion damage must be considered at high velocities. Proper materials, special linings, or replaceable wear plates must be incorporated to ensure good cyclone life.

The smaller the cyclone, the higher its efficiency. This widely held misconception often leads to improper cyclone selection or the use of a more complex dust collector when a simple cyclone will suffice. The size and efficiency relationship is applicable only when cyclones of the same family are considered. In Fig. 2, cyclone 1 is a high-capacity, medium-efficiency unit; cyclone 3 is a medium-to-low capacity, high-efficiency device. The data show that cyclone 3 is more efficient than cyclone 1, but it is also 48 percent larger.

But if inlet velocity or pressure drop is excessive in cyclone 1, a unit from another cyclone family can achieve the same efficiency at lower pressure drop and inlet velocity at a given set of conditions. For example, cyclone 2 has a 3.1 ft diameter, cyclone 3 a 6.5 diameter. An 8.7 ft diameter cyclone of the same family as cyclone 3 would have about the same efficiency as cyclone 2,

Fig. 2. Fractional efficiency curves of three high-performance cyclones show the effect of cyclone diameter and pressure drop on collection efficiency. Units 1 and 2 are high-capacity, medium-efficiency cyclones having 4.4 and 3.1 ft diameters, respectively. Cyclone 3 is a medium-to-low capacity, high-efficiency unit with 6.5 ft diameter. Pressure drop is 3.0 in w.g. for unit 1, 11.5 for unit 2, and 2.9 for unit 3. Air volume in all cases is 10,000 acfm, with 125 lb/cu ft dust density. Air density is 0.075 lb/cu ft, and viscosity is 0.018 centipoise. Dust loading is 85 lb/hr.



established by specifying the operating pressure drop and the desired collection efficiency. If the particle size distribution is unknown, efficiency may be expressed as the desired weight percent collection at one or more particle sizes. If the distribution is known, performance may be specified as a desired total collected weight percent or maximum allowable emissions to meet federal, state, or local needs.

Cyclone construction materials are generally determined by the abrasive and corrosive properties of the dust and gas. Operating temperature, pressure, wind loading, and seismic conditions also must be considered. Steel, nickel, and aluminum alloys can be used for corrosive conditions. Replaceable wear plates, as well as special linings of elastomers, refractories, and ceramics minimize the effects of abrasion. Pressure-relief safety devices and accesses to cyclone interiors to facilitate cleaning and maintenance can be provided.

Accessories such as scroll outlets, weather caps, dust receivers, feeder valves, structural supports, and manifolding for multiple cyclones are usually available from cyclone manufacturers. Any data pertaining to construction materials, equipment features, and accessories should be incorporated in the specifications. With reliable and accurate information—plus help from computers—manufacturers can design and construct cyclones precisely tailored to the user's needs.

Cyclone Costs—Equipment costs depend on performance requirements, construction materials, special features, and accessories needed for the application. In general, a single, large cyclone designed for a particular level of performance is less expensive than two or more smaller units operating in series or parallel providing the same efficiencies and pressure drops.

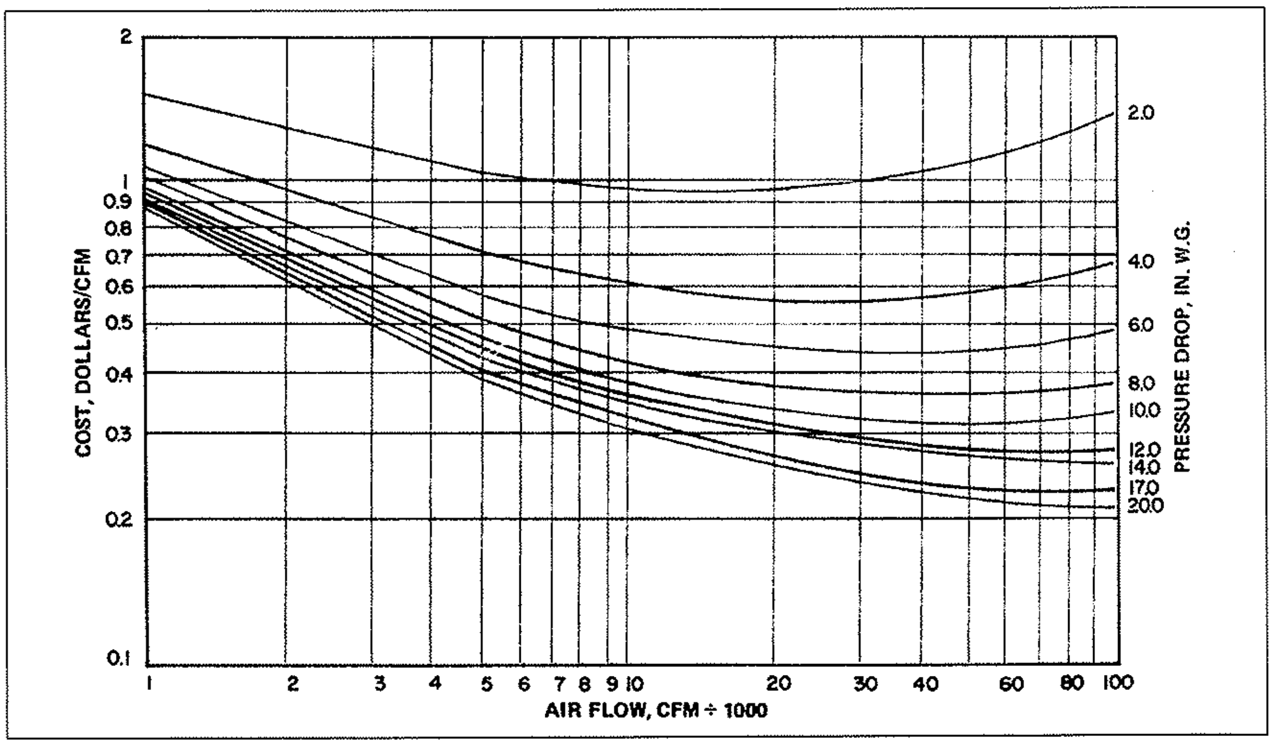
Figures 3 and 4 contain cost-comparison curves for single cyclones. Curves in Fig. 3 are based on a 6 in. w.g. pressure drop. Costs are shown as functions of air volume at various collection efficiencies. Curves in Fig. 4 denote 90 percent collection efficiencies at various pressure drops.

The following criteria are common to both illustrations:

- Material of construction is 10 gauge, all-welded mild steel.
- Gas is air at standard temperature and pressure
- Dust loading is 10 grains/acf
- Prices are for commercially available high-performance cyclones (1982)
- All cyclones are single units with no accessories or special design features (this condition may not always be practical).

The curves neglect factors such as costs for associated ductwork, air moving equipment, foundations, installation, and power, all of which must be included when overall project costs are determined. The curves do, however, illustrate graphically the cost-performance relationships and versatility of cyclone separators.

Fig. 4. Cyclone costs as functions of air flow at constant efficiency and various pressure drops are shown by these curves.Efficiency in all cases is 90 percent in collecting 5 micron particles with air at standard temperature and pressure. Dust density in the air passing through the cyclone is 168.5 lb per cu. ft.



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