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Before you design an inertial separator: Measuring your dust's aerodynamic particle size

Bill L. Heumann Fisher-Klosterman Inc.

Predicting how dust particles will act in an air (or other gas) stream — that is, their aerodynamic behavior — is all-important for designing cyclones and venturi scrubbers. Both of these dust control units operate as inertial separators, which must be designed for a dust's aerodynamic particle size distribution to successfully separate the particles from air. After introducing some aerodynamic particle size basics, this article gives practical information on measuring your dust's aerodynamic particle size, correlating sizing results, and using the results to design your inertial separator.

Among the design data you need for engineering and operating any type of dust control equipment, one of the most important is your dust's particle size distribution. But this is also among the most difficult data to collect. Not only is it hard to remove a representative sample from your process or exhaust airstream for size analysis, you must choose the right sizing method to ensure that the final data is suitable for designing your equipment.

Several methods for determining particle size distribution are available. Most of these are so-called *physical sizing methods* because they measure the particles' physical dimensions — the simplest, most direct form of particle sizing. One of the most common methods is sieving, which is used to measure larger particles (typically 44 microns or larger, depending on whether the method is wet or dry). Common methods for measuring smaller particles, including those in the submicron range, are microscopic examination and optical sensing.[1]

The problem is that knowing your dust particles' *physical* size won't help you predict how they'll behave inside a dust control unit known as an *inertial separator*. Common types of inertial separators include cyclones and venturi scrubbers.[2] In such a separator the dust particles are accelerated by centrifugal force in the separator's airstream. For instance, in a cyclone, as shown in Figure 1, the particles' inertia causes them to move towards the outer cyclone wall, where they're conveyed out of the airstream. To understand this aerodynamic behavior and predict how easily your particles will be collected in an inertial separator, you need to measure the particles' *aerodynamic particle size*. This data, along with your required dust collection efficiency, will help you design and size the equipment and estimate its cost.

Some aerodynamic particle size basics

While any of several instruments (described in a later section) can be used to measure aerodynamic particle size, each has the same general operating principle: measuring the velocity at which a particle moves through a gas or liquid while subject to a force. To provide accurate results, the measurement must allow time for the particle to reach a constant or steady-state velocity, called the *terminal velocity,* at which the acceleration forces on the particle are balanced by the drag forces on it.

The effect of these forces can be illustrated in a simple example: When a sky diver jumps from a plane, gravity applies acceleration forces to his body as he falls. If he never encountered air resistance during his fall, he'd continue to accelerate at 32.2 ft/s^2 until his parachute opened or he hit the ground. But in the real world, of course, the sky diver does encounter air resistance. This applies drag forces to his body and balances out the acceleration forces, causing his body to reach a terminal velocity at around 100 mph, depending on the body's position.

Terminal velocity and aerodynamic behavior. A particle's terminal velocity is more important than its other physical parameters in determining its aerodynamic behavior. In fact, two particles with radically different particle shapes, sizes, densities, and chemical compositions — such as a 10-micron coal fly ash particle and a peanut's brown skin — can have the same terminal velocity, allowing them to be collected equally well in a cyclone or venturi scrubber.

Because terminal velocity is the primary measure of particle aerodynamics, aerodynamic sizing determines a sample's *terminal velocity distribution*. For a given sample, for instance, the analysis may find that 5 percent of the particles have a terminal velocity of less then 1 ft/s, 10 percent have a terminal velocity less than 5 ft/s, and so on.

Simplifying aerodynamic size descriptions. Because it's confusing to describe samples by their terminal velocity distributions, we can apply Stokes law to equate terminal velocity with particle size. This lets us describe the particles' terminal velocity using *Stokes equivalent diameter:* the diameter of a spherical, homogeneous particle of a given density that will provide a specific terminal velocity.

Stokes law is expressed (in the most common range of Reynolds' numbers)[3] as:

$$U_t = \frac{Gd^2\,(p-g)}{18\,\mu}$$

where U_t is terminal velocity (in feet per second), G is gravitational acceleration (32.2 ft/s^2), d is the particle's Stokes equivalent diameter (in feet), p is particle density (in pounds per cubic foot), g is gas density (in pounds per cubic foot), and μ is gas viscosity (in pounds per feet per second).

If you measure U_t for a given particle, you can solve for the Stokes equivalent diameter using simple algebraic substitution. The result gives an aerodynamic particle size distribution for your sample. You can see an example in Table I, which is a calcium carbonate sample's aerodynamic particle size distribution in tabular form.

Figure 1

Inertial separation in a cyclone

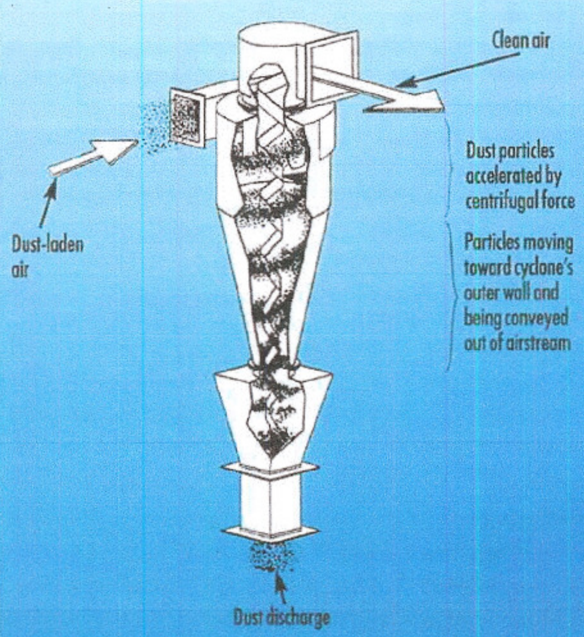

Table I

Aerodynamic particle size distribution for calcium carbonate sample[a]

Stokes equivalent diameter (microns)	Percent less than (by weight)
60.00	31.20
50.00	31.00
40.00	30.71
30.00	30.18
20.00	29.14
15.00	28.07
10.00	25.27
8.00	24.36
6.00	22.71
5.00	22.18
4.00	21.82
3.00	21.57
2.00	19.90
1.50	15.81
1.00	9.26
0.80	5.65
0.60	2.39
0.50	1.38
0.40	0.41

Note: Sample measured by liquid sedimentation.

Sample separation. Handling a sample can cause the particles to settle and separate by size over time. Make sure that samples tested by different instruments are well-mixed before testing and equally representative.

Number of sizing tests. Particle sizing isn't an exact science. No matter how carefully you prepare the samples, you need to test each sample enough times to ensure that your results represent a reasonably accurate statistical average.

Using the sizing results to design equipment

Work closely with your equipment supplier to design a cyclone or venturi scrubber that successfully collects your dust. The supplier will ask you to fill out a data sheet that supplies information about your dust and application requirements. In addition to asking for your dust's aerodynamic particle size distribution (and the test method used to measure it), the form typically asks for a physical description of your dust and its bulk density and whether it's corrosive, abrasive, sticky, explosive, or toxic. Other questions usually cover your process air (or other gas) conditions (including volume and moisture content), what type of equipment you're selecting, the dust load you expect at the equipment's inlet, and the dust collection efficiency the equipment must achieve.

The supplier will typically feed your aerodynamic sizing data to a computer that runs calculations to determine which equipment type and size will achieve your required collection efficiency at the conditions described on your data sheet. Knowing which aerodynamic sizing method was used is critical, because the computer calculations take differences in sizing methods into account.

The more accurate your aerodynamic sizing results are — particularly with finer dusts — the easier it is to correctly design and size the cyclone or venturi scrubber to meet your dust collection efficiency and cost requirements. How important is your separator's collection efficiency? It depends on how the equipment will function in your plant. For instance, for a cyclone that will serve primarily to capture dust and recycle it to your process, it's a matter of economics: The better the cyclone's collection efficiency, the more money you can save in product recovery. But with a cyclone or venturi scrubber that will provide emissions control to meet EPA Clean Air Act requirements, it's a matter of complying with the law: If the equipment's collection efficiency doesn't meet your requirements, your stack emissions can exceed your plant's allowable limit.

Cost considerations also come into play in correctly selecting and sizing the inertial separator. For instance, while a venturi scrubber that has a smaller pressure drop than you need won't provide your required collection efficiency, a scrubber that has a higher pressure drop than necessary — while meeting or exceeding your required collection efficiency — will cost more to purchase, install, and operate than you need to spend.

While measuring your dust's aerodynamic particle size will help you predict the dust's behavior in an inertial separator, partnering with your equipment supplier can help you turn that information into a separator that collects your dust without breaking your budget. **PBE**

Endnotes

1. With some physical sizing instruments, particle density or known specific gravity can be input to the instrument so that it calculates an aerodynamic particle size based on the measured (or assumed) particle characteristics. However, these results aren't accurate enough for predicting particle behavior in an inertial separator.

2. Settling chambers (knockout pots), core separators, and dynamic separators are less commonly used types of inertial separators. Aerodynamic classifiers also operate as inertial separators, but aerodynamic particle size alone isn't typically used to predict their performance; aerodynamic classifier performance is usually proven with pilot testing.

3. For more information on Stokes law, Stokes equivalent diameter, and related concepts, see subsection 20-7 in *Perry's Chemical Engineers' Handbook,* seventh edition, edited by Don W. Green, McGraw-Hill, 1997.

4. Bahco micro particle classifier; no longer commercially available.
5. For more information contact the American Society of Mechanical Engineers (ASME), Three Park Avenue, New York, NY 10016-5990; 212-591-7722, fax 212-591-7674 (www.asme.org).

For further reading

Find more information on particle size analysis and dust control in articles listed under "Particle analysis" and "Dust collection and dust control" in *Powder and Bulk Engineering*'s comprehensive "Index to articles" (in the December 2001 issue and at www.powderbulk.com).

Bill L. Heumann *is president and CEO of Fisher-Klosterman Inc., PO Box 11190, 822 South 15th Street, Louisville, KY 40251-0190; 502-572-4000, fax 502-572-4023 (wlh@fkinc.com). He holds a BS in oceanography from the Florida Institute of Technology in Melbourne.*