Cyclone separators are commonly the most attractive device for removing particles from gases, because of their relative ease of operation. Especially popular are reverse-flow devices with tangential or involute inlets. Unfortunately, engineers seeking to minimize capital outlay often modify the relative dimensions of a cyclone, thinking that the change will not affect performance. This can be a very costly assumption.

A basic rule in cyclone design and specification is as follows: Use only cyclones whose performance parameters (described below) have been determined or verified by actual testing on a cyclone of the same family, i.e., having the same geometry. For any given family, the ratios between the key dimensions of the cyclone remain constant.

Pressure drop, efficiency
The performance equations of a cyclone reflect two of its operating characteristics: the pressure drop through it, and its fractional-efficiency curve. The pressure drop, the difference in

<table>
<thead>
<tr>
<th>Outlet Pipe No.</th>
<th>Dimension &quot;A&quot; in Fig. 2, in.</th>
<th>% of Inlet penetration*</th>
<th>ΔP in. w.c.</th>
<th>Avg. % collection by weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3 13/16</td>
<td>50.0</td>
<td>11</td>
<td>90.65</td>
</tr>
<tr>
<td>2</td>
<td>6</td>
<td>78.7</td>
<td>11</td>
<td>92.75</td>
</tr>
<tr>
<td>3</td>
<td>7 11/16</td>
<td>100.8</td>
<td>11</td>
<td>93.32</td>
</tr>
<tr>
<td>4</td>
<td>9 11/16</td>
<td>127.0</td>
<td>10</td>
<td>93.91</td>
</tr>
<tr>
<td>5</td>
<td>11 1/2</td>
<td>150.8</td>
<td>11</td>
<td>92.95</td>
</tr>
</tbody>
</table>

*With reference to Figure 2, this column expresses (in percentages) the ratio between dimension "A" of the outlet pipe and the vertical dimension of the inlet duct, i.e., 7 5/8 in.
Tampering with the geometry to save money can be very costly in the long run.

William L. Heumann, Fisher-Klosterman, Inc.

Static pressure between inlet and outlet, is a measure of energy consumption. The fractional efficiency curve (see Figure 1) shows percent of particles collected as a function of particle size, and is the true indicator of a cyclone's ability to collect particulate. As with all inertial devices, cyclones generally collect larger particles more easily than smaller ones.

In a given application, the overall collection efficiency depends on the nature of the particulate. If we feed ball bearings into the collector corresponding to Figure 1, we expect 99.994% overall efficiency; with coal flyash, we look for only about 85%.

Still empirical

Environmental regulations and competitive pressures make accurate prediction of cyclone performance especially important nowadays. Pressure-drop calculations should be accurate to within ±5%. The calculated overall collection efficiency should either be accurate or lean slightly toward the conservative, so that the actual collection efficiencies will if anything be even better than predicted.

However, despite considerable effort, nobody has yet developed a theo-
retically based model that meets those criteria. So, cyclone specification and design is still based on empirical studies.

After accurate measurements of pressure drop and fractional efficiencies have been made during such studies, the results can be extrapolated to full-scale operating conditions so long as all of the geometric proportions of the cyclone are maintained — in other words, so long as the cyclone family does not change. If the designer, or the process engineer who specifies the cyclone, adheres to the family for which data are available, he or she may make a cyclone-performance prediction that is reliable at a new condition, using the known effects of changes in operating conditions and cyclone size on the pressure drop and efficiency curve.

The effect of deviating even slightly from the family can be very serious. Here are two examples, each involving small-scale versions of units in actual operation by our clients.

The case of the outlet pipe
The first example concerns a cyclone typical of those provided for fluid catalytic cracking in a petroleum refinery. This scale version (dimensions shown in Figure 2) represents what is often the secondary or tertiary stage in a multistage particulate-removal system and is by design intended for very high efficiency. In this test program, we used five different lengths for the gas outlet pipe (also called vortex finder) while holding all other dimensions constant, thus creating five families.

Random samples of a test dust having known characteristics were fed into the cyclone at a controlled rate. Pressure drop was measured and the collected dust weighed and analyzed for particle size distribution, allowing us to determine the fractional efficiency curve for each family. Summary results appear in Table 1.

Of particular interest are the data for pipes 2 and 4. The former is the one actually used in the client’s full-scale plant whereas the latter is the one that shows the best performance. Although the difference in percent collected is only 1.16% (i.e., 98.91% - 97.75), this can be meaningful indeed, whether the cyclone is used for product recovery or for environmental protection.

For example, if the inlet loading to the cyclone is 10,000 lb/hr, the emissions are 725 lb/hr with outlet pipe 2 and 609 lb/hr with pipe 4. Pipe 2 incurs an emission level that is more than 19% higher. If the particulate collected in the cyclone is worth $8.30/lb, the yearly cost of lost product is more than $200,000.

All five outlet-pipe configurations were also tested using very large particulates, plastic pellets. There was significant pellet carryover with outlet pipes 1 and 2, and slight pellet carryover with pipe 3. With pipes 4 and 5, particle collection was complete with no carryover. These results have implications for use of the cyclones in pneumatic conveying systems.

Apart from collection efficiency, there is a not-insignificant difference in pressure drop. In all tests, pressure drop is about 10% greater when an outlet other than pipe 4 was used. This can mean markedly higher annual energy consumption in larger units.

Why the temptation
There are at least two general situations in which the use of cyclones with shorter-than-optimum outlet pipes is encouraged by the process conditions. The first relates to high-temperature cyclones, such as might be used in fluidized-bed combustion systems. The pipes in these cyclones are of high-alloy construction and are extremely expensive — even a slight shortening can save significantly in the capital cost of the equipment.

The other situation involves relatively small refractory-lined cyclones, as might be used in catalytic cracking units. A high-quality lining is vital for acceptable operating life in the face of wear and tear due to catalyst ero-
Small modifications can cause big dips in performance

only cyclones of families whose performance predictions have been verified by actual testing. Two more-specific suggestions also emerge:
• Although our research does not justify the assertion that outlet pipes with less than 100% of inlet penetration are invariably less than optimum, all our tests showed optimum outlet-pipe penetration to range between 105% and 180%
• Cyclone with dished heads should not be used (unless they have internal false roofs so that the cyclone operates as if it had a flat roof)

Finally, it is important to follow the vendor's installation recommendations closely. If the vendor is not concerned with the inlet ducting and discharging arrangements for the cyclone, go elsewhere.

Edited by Nicholas P. Chopey

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