Basic Cyclone Design

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Introduction

• Brief history
• What is a cyclone?
  – A device that separates particulate from gas (fluid) by centrifugal force
  – Works simply by the kinetic energy of the incoming mixture (flow stream) and the geometry of the cyclone
How Cyclones Work: Nomenclature
How cyclones work

• All cyclones work by centrifugal force
• Two main factors affect cyclone efficiency
  – velocity particle moves towards the wall or collection area of the cyclone where it is theoretically collected
  – length of time available for collection: Residence Time
• Two main metrics describe cyclone performance
  – Pressure drop
  – Fractional efficiency curve (FEC)
How Cyclones Work: Basic Flow Patterns (Reverse Flow Cyclone)
Another Kind of Cyclone
How Cyclones Work: Basic Flow/Pressure Patterns

- **Tangential Velocity**
- **Axial Velocity**
- **Static Pressure**
Different styles of Cyclones: Inlet Designs
Different Arrangements of Cyclones

Parallel Arrangement
Different Arrangements of Cyclones: Series Arrangement
Parallel Cyclones
Parallel Cyclones
Different styles of cyclonic devices

Parallel Cyclones
Reverse Flow-Axial Inlet
Series Cyclone Arrangement
FCC Process: The heart of the system
FCC Regenerator Cyclones
Pressure Vessel Cyclones
A cyclone picture of another sort..
Why Use Cyclones?

• Dry
• No moving parts
• Robust Construction
• Can be easily designed for very severe duty (examples)
• Low cost (sometimes)
• Safety
When do you use a cyclone?

• When it is the most economical solution!
  – Capital Costs
  – Installation Costs
  – Operating Expenses
  – Maintenance Expense
  – Depreciation (life expectancy)
  – Safety and liability issue
  – Product recovery
  – System operability
  – Effects on downstream equipment and process
Cyclone Performance Metrics: Pressure drop

- Pressure drop = power consumption
- Pressure drop measurement

\[ \Delta P = P_{a \text{ inlet}} - P_{a \text{ outlet}} \]

where;

\[ \Delta P = \text{cyclone pressure drop} \]
\[ P_a = \text{absolute pressure} \]
Where Does Pressure Drop Come From?

- Frictional and entrance losses usually = 10%-30% of total
- The rest is the pressure gradient generated by the vortex
Pressure drop @ no load

- Basic pressure drop equation

\[ \Delta P_2 = \Delta P_1 \cdot \left( \frac{Q_2}{Q_1} \right)^E \cdot \left( \frac{\rho_2}{\rho_1} \right) \]

where:

- \( Q \) = gas flow rate
- \( E \) = geometry exponent (1.9-2.3)
- \( \rho \) = gas density
Pressure drop @ load

• Pressure drop goes down with increased dust load

• Pressure drop dust loading equation

\[ \Delta P_L = C \cdot \Delta P_0 \]
\[ C = 2.095 \cdot W^{-0.02} - 1.09 \]

where;

\( \Delta P_L = \text{pressure drop @ load} \)
\( \Delta P_0 = \text{pressure drop @ no load} \)
\( W = \text{dust load (grains/acf)} \)
Fractional efficiencies

- collection efficiency @ various particle sizes
- fractional or size efficiency curve
- may be graphical or tabular
Example Size Efficiency Curve

<table>
<thead>
<tr>
<th>Particle Diameter (microns)</th>
<th>% collection (B.W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>3</td>
<td>74</td>
</tr>
<tr>
<td>5</td>
<td>92</td>
</tr>
<tr>
<td>10</td>
<td>98.74</td>
</tr>
<tr>
<td>30</td>
<td>99.4</td>
</tr>
<tr>
<td>50</td>
<td>99.8</td>
</tr>
<tr>
<td>100</td>
<td>99.99</td>
</tr>
</tbody>
</table>

% Collection (By Weight)

Particle Size (Microns: Stoke Eq. Diameters)
FEC Variables

- Cyclone Geometry
- Cyclone Velocities
- Particle Density
- Gas Viscosity
- Dust Load
Cyclone Total Collection Efficiency

- Function of the cyclone FEC and incoming Particle Size Distribution (PSD)
- Cyclone Total Collection Efficiency can vary greatly but it may be doing exactly the same thing!
## Total collection efficiency sample calculation

<table>
<thead>
<tr>
<th>particle size range (microns)</th>
<th>particle size distribution (% by weight)</th>
<th>d50 (microns)</th>
<th>fractional efficiencies collection (% by weight)</th>
<th>collected particulate (% by weight)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 - 5</td>
<td>3</td>
<td>2.5</td>
<td>25.96</td>
<td>0.78</td>
</tr>
<tr>
<td>5 - 10</td>
<td>5</td>
<td>7.5</td>
<td>94.83</td>
<td>4.74</td>
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<tr>
<td>10 - 20</td>
<td>12</td>
<td>15</td>
<td>98.79</td>
<td>11.85</td>
</tr>
<tr>
<td>20 - 30</td>
<td>19</td>
<td>25</td>
<td>99.28</td>
<td>18.86</td>
</tr>
<tr>
<td>30 - 40</td>
<td>13</td>
<td>35</td>
<td>99.87</td>
<td>12.98</td>
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<tr>
<td>40 - 50</td>
<td>12</td>
<td>45</td>
<td>99.94</td>
<td>11.99</td>
</tr>
<tr>
<td>50 - 70</td>
<td>11</td>
<td>60</td>
<td>99.99</td>
<td>11.00</td>
</tr>
<tr>
<td>70 - 90</td>
<td>10</td>
<td>80</td>
<td>100.00</td>
<td>10.00</td>
</tr>
<tr>
<td>90 - 110</td>
<td>7</td>
<td>100</td>
<td>100.00</td>
<td>7.00</td>
</tr>
<tr>
<td>110 - 130</td>
<td>6</td>
<td>120</td>
<td>100.00</td>
<td>6.00</td>
</tr>
<tr>
<td>130 - 150</td>
<td>2</td>
<td>140</td>
<td>100.00</td>
<td>2.00</td>
</tr>
<tr>
<td><strong>Totals</strong></td>
<td><strong>100</strong></td>
<td></td>
<td><strong>97.21</strong></td>
<td></td>
</tr>
</tbody>
</table>
Tools for Increased Cyclone Efficiency: Cyclone Geometry Variables

- Inlet configuration and ratio
- Cyclone L/D Ratio
- Outlet pipe penetration
- Dust receiver
- Residence time
Tools for Increased Cyclone Efficiency: High Residence Time

High Capacity/Low Residence Time

High Residence Time/Low Capacity
Tools for Increased Cyclone Efficiency: Parallel Cyclone Arrangements

- One of best tools for getting higher collection efficiency: For a given power consumption and family of cyclones, splitting the flow into parallel streams allows the use of more efficient, smaller cyclones: “Small Cyclones are more efficient than large ones.”
- Parallel arrangements may provide the best solution when headroom is limited
Tools for Increased Cyclone Efficiency: Parallel Cyclone Arrangements
Tools for Increased Cyclone Efficiency: Series Cyclone Arrangements

- Can provide higher collection efficiency for a limited inlet velocity because of the cumulative efficiency: 90% @ 5 micron + 90% @ 5 micron = 99% @ 5 micron
- May provide for redundancy in the event of system upsets
Tools for Increased Cyclone Efficiency: Tangential (Radial) Velocity

\[ F_c = m \cdot \frac{V_t^2}{r} \]

VELOCITY VS. FORCE

CL DISTANCE (METERS)

TANGENTIAL VELOCITY (M/S)
CENTRIFUGAL FORCE (G'S)
Tools for Increased Cyclone Efficiency: Tangential Velocity and/or Centrifugal Force

• How do we increase Tangential Velocity?
  – Increase Inlet Velocity
  – Increase Outlet Velocity

• What else can we do to increase Centrifugal Force?
  – Smaller radius flow path: Use parallel cyclones
  – Decrease outlet pipe diameter
Other Tools for Increased Efficiency: Geometry

- L/D Ratio
- Inlet Design
- Optimum Outlet Pipe Length
- Dust Receivers
Other Tools for Increased Efficiency: Arrangement

• Cyclones in Parallel
  – Takes advantage of rule that says “for cyclones of the same family (geometrically proportional) at the same operating conditions, smaller cyclones are more efficient than larger ones

• Cyclones in Series
  – Redundant chances for particle collection
The Costs of Increased Efficiency: High Residence Time Cyclones

- Capital Cost
- Headroom
- May not be possible or viable with some processes
The Costs of Increased Efficiency:
Parallel Cyclones

• Capital Costs
• Manifolding can be expensive and difficult
• Pneumatic isolation can be difficult or cost prohibitive
• More horizontal space required
The Costs of Increased Efficiency: Series Cyclones

- Capital Costs
- Manifolding can be expensive and difficult
- More horizontal space required
- Pressure Drop is Cumulative
- Diminished benefit as PSD gets smaller
The Costs of Increased Efficiency: Increased Velocity

- Pressure Drop (Power Consumption)
- Erosion
- Particle Attrition
- Re-entrainment
- At very high velocities may have acoustical and/or Ranque-Hilsch effects
How Cyclones Fail

• Improperly Designed
  – Incorrect or inaccurate design data
  – Lack of know how by cyclone designer- after all, “anyone can build a cyclone”

• Leakage into the cyclone

• Plugged cyclones

• Cyclones wear out too quickly
How Cyclones Fail: Design/Fabrication Errors

- No dust receiver
- Short outlet pipes
- Dished heads
- Poor or non-existent airlocks
- Instruments or access ports installed into cyclonic flow streams
- Related equipment not designed for cyclonic flow
- Inlet elbows, transitions, or other obstructions
• For More Information Visit 
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