THIRD STAGE CYCLONE SEPARATORS
AN ALTERNATIVE FOR PARTICULATE RECOVERY

Abstract
Gases leaving a Fluid Catalytic Cracker Regenerator normally have a catalysts loading between 200 mg/Nm^3 and 300 mg/Nm^3. In many countries, this loading must be reduced to less than 50 mg/Nm^3 before the gases are discharged into the atmosphere. To accomplish this, many use electrostatic precipitators (electro filters) or wet gas scrubbers, but some use cyclone separators. This presentation lists the options and limitations one must consider when deciding whether or not to use a cyclone separator, frequently called a third stage cyclone separator, as the final particulate collection device. Since there are several types of cyclones and several ways the cyclones can be arranged in the separators, the advantages and disadvantages of the different types of cyclones and cyclone arrangements are presented.

Third Stage Cyclone Separators – An Alternative for Particulate Recovery

What Are Third Stage Separators?
This name has been applied to the several types of cyclonic particulate recovery systems that are located outside of fluid catalytic cracker regenerators. The name comes from the fact that these cyclonic systems receive the gases that have passed through two stages of cyclones located inside the regenerator vessels. Many third stage cyclones receive gases directly from the regenerator at the outlet temperature and pressure. However, some cyclone systems have been located down stream of the waste heat boilers. At this point, the gas volume is smaller because the gas temperature has been reduced but not the gas pressure. Other cyclone systems have been installed next to the exhaust stacks where the gas temperature is 230° to 315° C (450° to 600° F) and the gas pressure is nearly ambient.

In most installations, the cyclones are installed inside of pressure vessels, but there are some installations where cyclones with diameters between 1.0 and 1.5 m (40 and 60 in.) are designed and installed as individual pressure vessels.

Why Should One Consider Using Cyclones to Meet Environmental Requirements for Particulate Emissions?
The simple answer is cost savings, both capital costs and operating costs. Currently most particulate collection to meet environmental requirements is done with electrostatic precipitators (electro filters). More recently, some refiners have installed wet scrubbers to meet the requirements for both particulate and sulfur oxide recovery. However, to do this a two stage scrubber must be used because the scrubbing process for particulate recovery and the scrubbing process for sulfur oxide recovery are two different processes. Thus, even if a scrubber is required for sulfur oxide recovery, third stage cyclones may be a way to save the capital and operating costs of the particulate scrubbing section.

Some refiners may consider the installation of third stage cyclones to reduce the particulate loading to an electrostatic precipitator that is to small for the current gas rate. However, before doing this one should talk with the supplier of their precipitator. The concern is the third stage cyclones will collect the coarser particles, so the precipitator will only receive very fine particles. With a high velocity in the precipitator and no coarse particles, the fine particles may be swept off the collecting plates by the gases instead of falling into

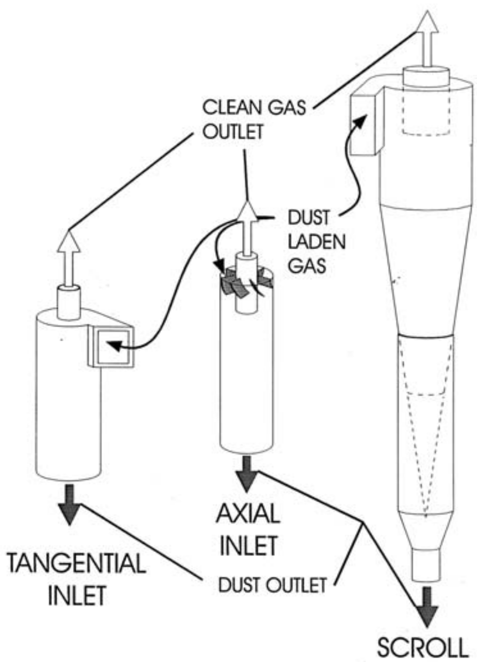


FIGURE 1

hoppers. Some refiners with power recovery units and precipitators have found that when the catalyst collected in the third stage cyclones was re-injected into the gas stream ahead of the precipitator, the losses from the precipitator decreased.

What Types Of Cyclones Are Used In Third Stage Cyclone Systems?

Three types of cyclones are presently being used in third stage cyclone systems (shown on Figure 1.).

The first type is cylindrical cyclones about 0.25 m (10 in.) in diameter that have axial inlets. Gases enter the top of each cyclone through the annular space between the cyclone wall and the gas outlet tube. Turning vanes in the top of the cylinder cause the gases to spin inside the cyclone. The solids discharge is either out the bottom of the cylinder or through vertical slits in the lower portion of the cylinder.

The second type is cylindrical cyclones about 0.25 m (10 in.) in diameter each with a tangential inlet at the top of the cylinder. The gases enter the cylinder under the cyclone roof, pass between the outside of the gas outlet tube and the inside of the cylinder wall and spin downward along the cylinder wall. The solids discharge is either out the bottom of the cylinder or through vertical slits in the lower portion of the cylinder.

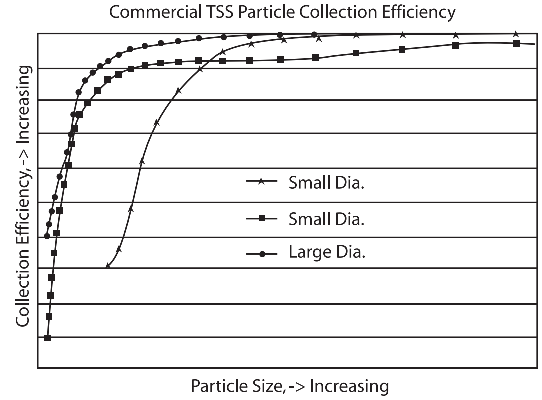
The third type is "large diameter" cyclones with scroll inlets. Each cyclone has an upper cylindrical section between 0.9 and 1.3 m (35 and 50 in.) in diameter, a conical midsection and a hopper on the bottom. The gases enter at the top of the cyclone cylinder tangentially through a scroll that is offset from the side of the cylinder. Thus, where the gases pass the gas outlet tube there is space between the gas stream and the outlet tube. The solids discharge out the bottom of the hopper through a length of pipe and sometimes through a discharge valve.

Do The Different Types Of Cyclones Perform Differently?

There are significant performance differences between each of the three separators. The following are the overall collection efficiencies that we and others have measured at normal operating conditions for the three types of separators:

Type	Efficiency
10" (.25 meter) axial inlet	40 to 60%
10" (.25 meter) tangential inlet	50 to 65%
40" (1 meter) scroll inlet	70 to 85%

Differences in the collection efficiencies at specific particles sizes for each of the three types of cyclone separators are shown on the attached graph entitled Commercial TSS Particle Collection Efficiency prepared by an oil company with all three types of separators in their refineries.



What Limits The Collection Efficiency Of Cyclones?

The items which one normally considers as limiting factors for cyclone efficiency, include:

- Cyclone geometry
- Cyclone diameter
- The particle size analysis of the entering particles
- The density of the particles
- The quantity of entering particles
- The inlet velocity
- The outlet velocity
- The viscosity of the gas

Much has been written about these items. However, there are some other less understood factors which limit cyclone efficiency. When a number of cyclones, each with a different inlet particle loading, discharge into a common hopper, the pressures at the cyclone discharge outlets are different. To balance these differences, gases flow from the cyclones with higher pressures into the cyclones with lower pressures. When gases enter a cyclone outlet opening, they re-entrain some of the collected particulates and carry them out of the cyclone. This reduces the overall efficiency of the separator.

How Do Other Gas-Particle Cyclone Interactions Affect Particulate Recovery In Cyclones?

Gas-particle-cyclone interactions establish a minimum amount of particles that will remain in the gases. When the quantity of particles remaining in the cyclone gases reaches a level of about 45 mg/Am^3 (2.8x10-6 lb/Aft^3), collection of particulates in the cyclones stops. When performance design data, which does not consider this limit, predicts lower particulate losses, one will find that the predicted performance is not achieved. However, one will also find that the loading to the cyclones can be increased until the predicted losses equal the above limit without any increase in losses.

Why Is A Separator With 1 Meter (40" Diameter Cyclones More Efficient Than A Separator With 0.25 Meter (10") Diameter Cyclones?

First, there are fewer 1.0 m (40 in.) diameter cyclones in one separator vessel, usually 8 to 20 cyclones, compared to 80 to 200 small diameter cyclones in one vessel.

Second, in a vessel with large diameter cyclones the gases and catalyst are ducted from the vertical inlet nozzle in the center of the vessel into each cyclone inlet. Thus, the gases and catalyst particles have nearly equal distribution into each cyclone. In vessels with small diameter cyclones the gases and particles are discharged from the vertical inlet nozzle into a chamber. While there is little difference in volume of gas entering each cyclone, the majority of the particles enter the cyclones near the point of discharge. This is the major reason for the pressure differences at the cyclone outlets in the collection hopper. To reduce the amount of gases that circulate between small diameter cyclones 1 to 3 percent of the gases entering a separator are drawn off the bottom of the vessel with the solids. However, there is still a large amount of gas circulation between cyclones.

Third, the catalyst leaving each large diameter cyclone cone enters a final separation hopper on the cyclone and then travels down a pipe or "dipleg" from which it discharges into the vessel. In some units the catalyst leaving each dipleg passes through a check valve that opens only to discharge the catalyst. Thus, gas leakage into the large diameter cyclones is essentially eliminated. Therefore, it is not necessary to withdraw gases from the vessel or "common hopper" to improve cyclone efficiency, but gases may be withdrawn, if this is the preferred way to convey the collected catalyst to a storage hopper.

What Does a Third Stage Cyclone Separator Designed For Air Pollution Control Look Like?

Figure 2 shows a large diameter cyclone system were 1 to 2 percent of the entering gases are drawn off the bottom of the vessel to convey the collected catalyst to a "fourth stage" cyclone. The "fourth stage" cyclone separates the catalyst from the conveying gases and discharges it into a fines unloading or storage hopper. Normally, the catalyst is sufficiently cooled in the uninsulated conveying line for discharge into a truck or hopper, but cooling air can be injected into the storage hopper, if necessary. The gases from the "fourth stage" cyclone pass through a critical flow orifice where the gas pressure is reduced before the gases are discharged into the regenerator flue gas line or stack.

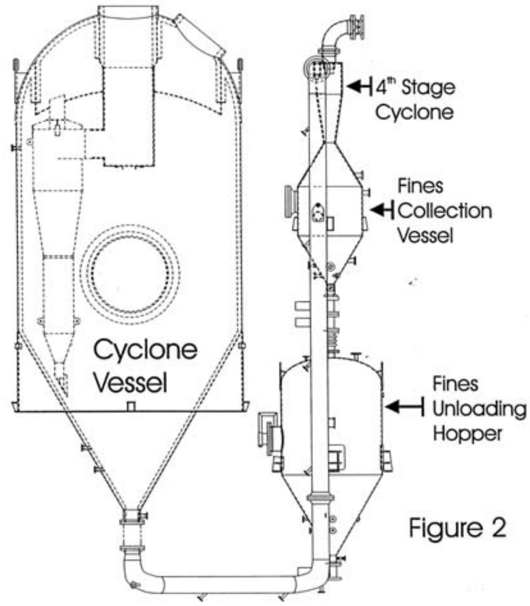
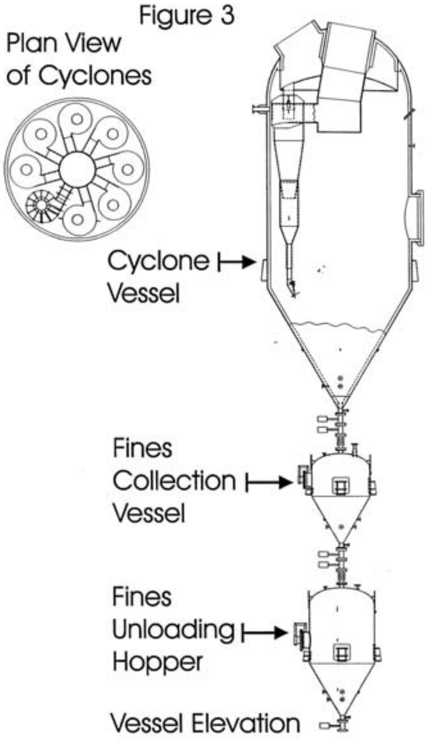


Figure 2

Figure 3 shows a large diameter cyclone system were there is no gas withdrawal because the collected catalyst falls directly into the fines unloading or storage hopper. The hopper has provisions for the introduction of cooling air.

Figure 3



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What is the Preferred Location For a Third Stage Cyclone Separator Downstream From the Regenerator?

When the only purpose of the separator is air pollution control and there is a waste heat boiler before the slide valve, the separator should be located between the waste heat boiler and the slide valve. The advantages of this location are:

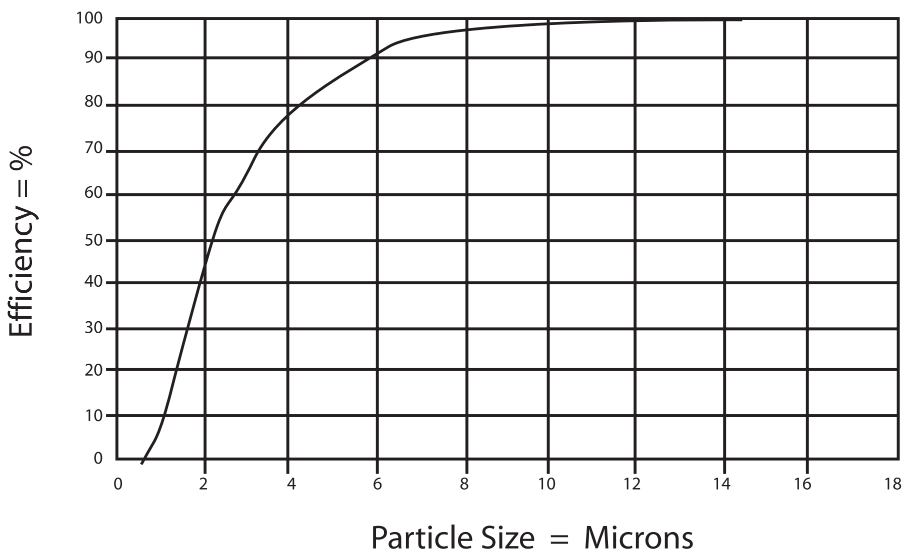
- The gas volume is smaller because of the lower gas temperature.
- The size of the separator is reduced because of the smaller gas volume.
- Thermal stresses in the separator are less because of the lower operating temperature.
- The particles dislodged from the boiler tubes during soot blowing enter the cyclones.

When the primary purpose of the third stage separator is protection of an expander turbine, the separator must be located between the regenerator and the turbine.

How Does One Estimate the Efficiency of Large Diameter Third Stage Cyclones?

The cyclone supplier should provide a Fractional Efficiency Curve for the collector when it is operating at the specified operating conditions. The refiner should have particle size analyses of the catalyst escaping the regenerator. With this information the cyclone supplier will calculate the collector efficiency. The following is a typical fractional efficiency curve for large diameter third stage cyclones.

Typical Fractional Efficiency Curce for
Large Diameter Third Stage Cyclones



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