THIRD STAGE SEPARATORS

What Are Third Stage Separators?

While this name could apply to any particulate collection device that follows the two stages of cyclones in a fluid catalytic cracker regenerator, it is most frequently used to designate a group of cyclone separators. Thus, the gases are at the regenerator outlet temperature and pressure. However, some separators have been located after waste heat boilers where the gas volume is reduced because the temperature is lower but the pressure is essentially unchanged. Also, some separators have been installed ahead of the exhaust stack where the temperature is 450° to 600° F (230° to 315° C) and the gauge pressure is nearly zero.

Most cyclonic elements operating at high pressure are installed in a pressure vessel, but there are some installations of cyclones between 40 and 60 inches (1.0 to 1.5 meters) in diameter where the individual cyclones are pressure vessels.

What Is The Purpose Of A Third Stage Separator?

The original purpose was to remove catalyst particles 10 microns and larger from the regenerator exhaust gases so that these gases could then be passed through an expander turbine for the generation of electricity. Later, when environmental regulations required that particulate emissions from regenerators be reduced, third stage separators were used for this purpose. Presently, some third stage separators are meeting the required particulate collection for both power recovery and emission control.

What Types Of Cyclones Are Used In Third Stage Separators?

Three types of cyclones are presently used in third stage separators (shown in Figure 1.):

- The first type is axial inlet cyclones about 10 inches (0.25 meters) in diameter. Gases enter the top of each cyclone through the annular space between cyclone wall and the gas outlet tube. Turning vanes in the entrance cause the gases to spin in the cyclone.
- The second type is tangential inlet cyclones about 10" (0.25 meters) in diameter. Gases enter tangentially at the top of each cyclone and pass beside the outside of the gas outlet tube.
- The third type is scroll inlet cyclones, usually between 35 and 50 inches (0.9 and 1.3 meters) in diameter. Gases enter tangentially through a scroll that is offset from the cyclone wall so that there is space between the gas outlet tube and the entering gases as they pass beside the outlet tube.

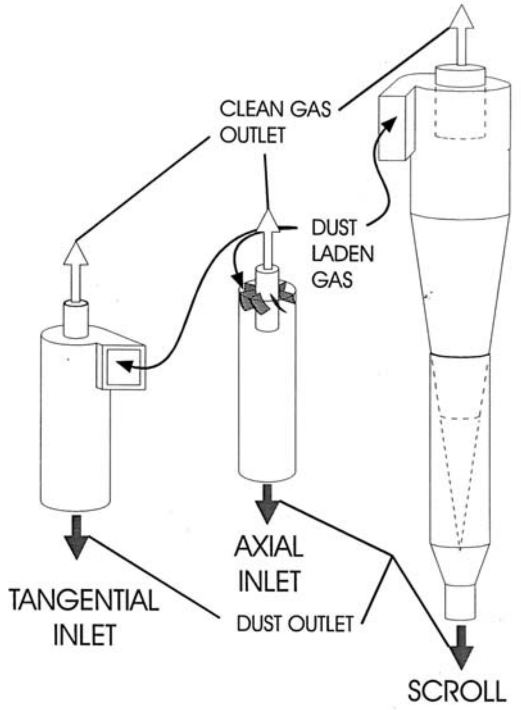

FIGURE 1

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Do The Different Types Of Cyclones Perform Differently?

There are significant performance differences among the three types of cyclone separators. On operating units, when the regenerator losses were considered normal, we measured the following overall collection efficiencies for the three types of cyclonic 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%

However, more significant are the performance differences observed during periods of upset operation when the regenerator losses are very high. High loadings of catalyst tend to plug some of the cyclones in separators with either 10 " (0.25 meter) axial inlet cyclones or 10" (0.25 meter) tangential inlet cyclones. The result is a significant increase in catalyst losses from the separators. More importantly, for separators preceding expander turbines, the percentage of particles greater than 10 microns increases from less than 2% to more than 20%. Even when the upset lasts only a short time, some will observe erosion on the blades of the expander turbine. On the other hand, 40" (1.0 meter) diameter scroll inlet cyclones show a negligible increase in both losses and the percentage of particles greater than 10 microns in the exit gases. Regenerators have operated for up to 30 days feeding losses of more than 10 times the normal losses to scroll inlet cyclone without any observable erosion on the expander turbine blades.

Another performance difference explains why at normal operation the smaller types of cyclones are able to have losses with less than 2% of the particles greater than 10 microns, even though the collection efficiencies are less than those in the larger diameter cyclones. This difference is the amount of catalyst attrition that occurs in the smaller cyclones. An analysis of a normal sample from a third stage cyclone inlet will show an average particle size of about 12 microns. When one then uses the analyses of samples from the catch and losses of small diameter cyclones to reconstruct the analysis of the catalyst entering the cyclones, one will find that the reconstructed feed has an average particle size of about 8 microns. On the other hand, if one compares the reconstructed inlet analysis of samples from the catch and losses of large diameter cyclones with the analysis of a sample from the cyclone separator inlet, they will find little or no difference between the two analyses.

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 quantity of entering particles
- The inlet velocity
- The outlet velocity
- The gas viscosity

Much has been written about these items. However, there are some other less understood factors which also limit cyclone efficiency. One limit is the result of gas circulation in the common hopper that collects the catalyst from all of the cyclones. Another limit is set by Brownian motion and other gas-particle interactions.

How Does Gas Circulation In A Common Collection Hopper Limit Cyclone Efficiency?

The background for the answer to this question is the following: When two cyclones that are proportionally similar are tested on an individual basis, the cyclone with the smaller diameter will be more efficient. This is the principle which people use as the basis for the design of third stage separators with multiple small diameter cyclones discharging into a common catalyst collection hopper or duct.

What was overlooked in this design is the pressure drop variations that occur between the cyclones. When gases with particulates that are not homogeneously distributed enter a multiple cyclone collector, the solids loading to the individual cyclones will vary. When particles are collected in a cyclone, there is some energy recovery as the particles slow down during collection that is transferred to the gases as a reduction in pressure drop. When multiple cyclones discharge into a common hopper, the pressure drop from the inlet to the hopper is less for the cyclones with higher particulate loadings than it is for the adjacent cyclones with lower particulate loadings. To compensate for this, some of the gases from the cyclones with the lower loadings exit the cyclones with the collected particles and enter the outlets of the cyclones with the higher loadings. These entering gases re-entrain some of the collected particles and carry them up the center and out of each cyclone. As the number of cyclones discharging into a common hopper increases the amount of particulate re-entrainment by recirculation increases. The affect of this gas circulation can be reduced by withdrawing gases from the hopper and ducting them to another particulate collector, but for collectors with a large number of cyclones, the amount of gas that must be withdrawn can be as high as 10% of the total volume. If one plans to pass the gases through an expander turbine, the resulting power loss will normally be unacceptable.

How Do Brownian Motion And Other Gas-Particle Interactions Affect Particulate Recovery In Cyclones?

When the quantity of particles remaining in the cyclone gases reaches a level of about 3.0 x 10-6 lb/Aft^2 (48 mg/Am^3) collection of particulates in the cyclone stops because of Brownian motion and other gas-particulate interactions. When performance design data, which does not consider this limit, predicts a lower particulate loss, 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 loss equals the above limit without any increase in losses.

Because the loss from a third stage separator in mg/Nm^3 is usually higher than the loss in mg/Am^3, one can see that a cyclone separator will probably not meet a requirement that losses be less than 50mg/Nm^3. However, on most units the cyclone separator should be able to meet a requirement that losses be less than 75 $mg.Nm^3$.

What Type Of Third Stage Separator Is Best?

This question will certainly have different answers from different suppliers, but our answer is scroll inlet cyclones with a diameter of about 40 inches (1.0 meters) installed in a pressure vessel. Figure 2 shows the system which is used by the majority of our clients. The cyclone vessel would normally have between 8 and 20 cyclones, depending on the volume of gas entering the cyclone vessel. The gases enter through the center nozzle in the vessel had and are symmetrically ducted to the cyclone inlets for good gas distribution. The cyclone outlet ducts discharge into a common annular plenum around the inlet duct. The gases exit the cyclone vessel through the inclined nozzle to the right of the inlet nozzle. Each cyclone has a hopper and dipleg with either an inclined splash plate or a discharge valve. The cyclone vessel which is the common hopper for the cyclone catalyst discharge is designed to hold the catalyst collected over several days. However, normally the catalyst from the cyclone vessel is continuously conveyed to the 4th stage cyclone by a small amount of gas, usually from 1 to

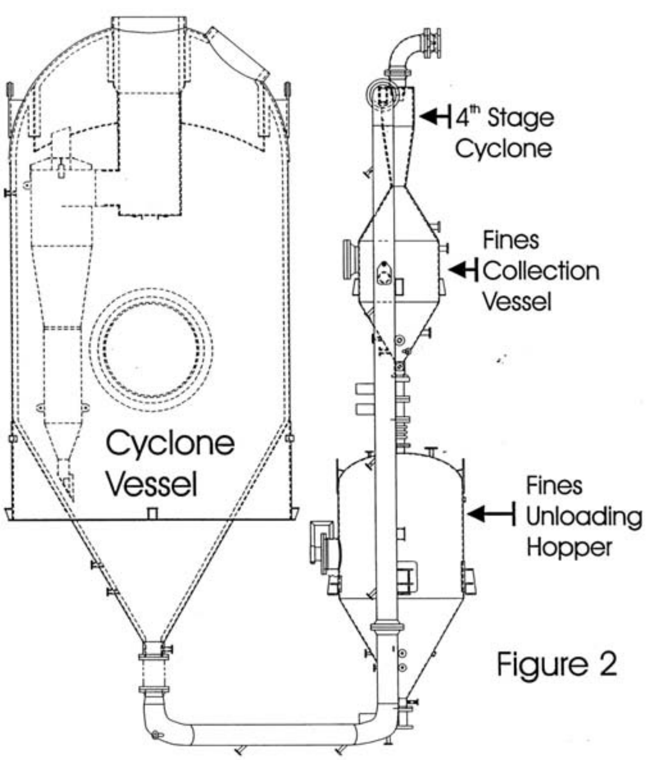

Figure 2

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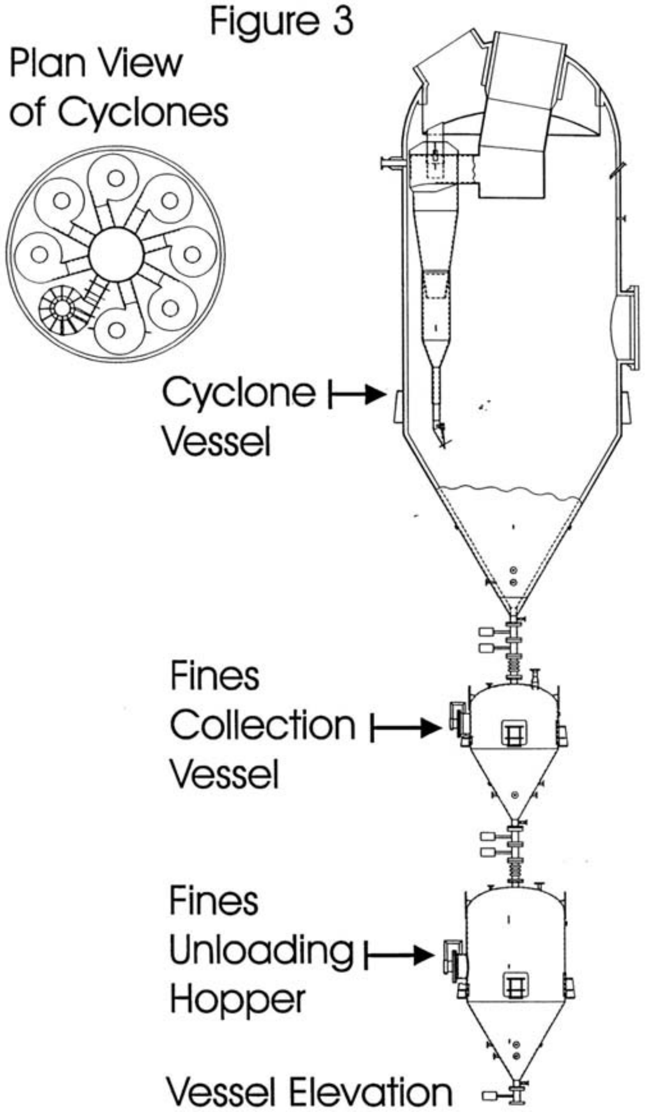
3% of the gases entering the cyclones. During the travel through the uninsulated line and the 4th stage cyclone, a considerable amount of heat is lost from the catalyst and gases. Additional cooling of the catalyst occurs in the fines collection vessel. The gases from the 4th stage cyclone pass through a critical orifice where the gas pressure is reduced for discharge through the stack. When the fines collection vessel is to be emptied into a closed truck for transport to a landfill, the valve above the vessel is closed, a vent valve is opened to relieve the pressure, and the valve beneath the vessel is opening so that the catalyst may discharged into the truck.

The arrangement shown on Figure 3 was supplied to an Asian Refinery located near the equator for air pollution control. The cyclone vessel, which has eight (8) cyclones with valves on the diplegs, is similar to the one on Figure 2. However, there is no 4th stage cyclone, because this system is designed for no withdrawal of gases. Instead, the catalyst from the cyclone vessel discharges directly into the fines collection vessel. When the fines collection vessel is full, the valve above the fines collection vessel is closed and air is blown into this vessel to cool the collected catalyst. The cooling air is ducted to the inlet of the cyclone vessel. After the catalyst is cooled, the valve under the fines collection vessel is opened and the catalyst is discharged into the fines unloading hopper. When all of the catalyst has been discharged from the fines collection vessel, the valve beneath the fines collection vessel is closed and the valve above the fines collection vessel is opened so that the process may be repeated. Catalyst accumulates in the fines unloading hopper until it is discharged into a closed truck and transported to a landfill area.

Figure 3



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