

# FLUID CATALYTIC CRACKING CYCLONE DESIGN AND MODIFICATIONS

The relative importance of cyclones in fluid catalytic cracking units (FCCU) is right behind that of reactors and regenerators, because catalysts must be separated economically from reactor and regenerator gases. Cyclone system designs have changed frequently over the past 56 or so years that refiners have operated FCCUs such that cyclones can withstand increasingly more severe operating conditions longer in refiners' quests to increase run lengths.

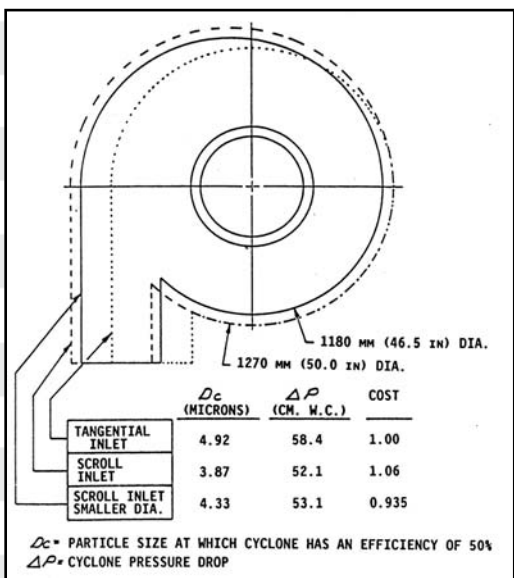
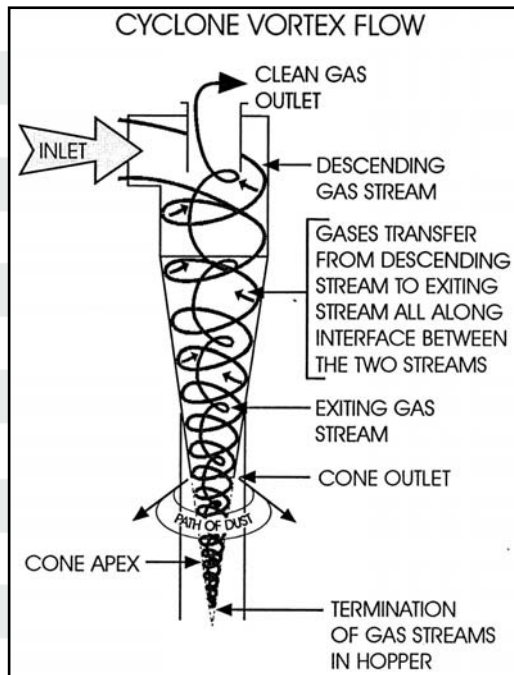
## Cyclones

Typically cyclones are inverted cones (with their points cut off) designed such that a catalyst and gas mixed stream enters the base of the cone, which is at top of the cyclone, along the inside wall. The mixed stream is thrust out against the inside wall as the stream moves down the cone into the narrower sections. Catalysts, being solid particles, continue on a spiral roll down the cyclone wall as gas separating from catalyst flows up through the center of the cyclone to exit at the top. Catalyst exits from the cyclone bottom. Today's FCCU cyclones consist of a cone, whose truncated tip is fit over a cylinder, which is terminated by a diameter reducer followed by another smaller cylinder which descends toward where catalyst is deposited. See an illustration of such a cyclone unit at the end of this Notebook.

This is a simple explanation of a device that operates efficiently only when the number of cyclone stages, the number of parallel cones, diameters, angles, lengths, wall thicknesses, materials of construction and support systems are properly chosen.

## Cyclone Inlets And Bodies

Tangential inlets to cyclones project gas and particles into the cyclone along the inside wall. However, the inlet opening is wide enough for inlet particles to impinge upon the gas outlet tube, which must extend down through the top of the cyclone far enough to prevent inlet gas and particulates from mixing with separated outlet gas. By pushing the inlet portion of the cyclone wall away from the cyclone center, the entering inlet gas and particle stream will be kept away from the gas outlet tube entrance and the gas outlet tube external wall. This extension of the cyclone wall away from the cyclone center is called an inlet scroll and increases initial regenerator cyclone system costs by about 2% and the initial cost of a single stage-system by about



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4%. While large, and consequently heavier, particles upon entering typically stick to the cyclone wall, small, and consequently lighter, particles upon entering take a path between the cyclone wall and the center of the cyclone. If a smaller particle enters the cyclone below the gas outlet tube ultimately ricocheting into the outlet gas stream, the cyclone's separation efficiency will be reduced. At any height within a cyclone, gas will be changing from descending with particles to ascending into the outlet gas stream due to the decreasing cone diameter with increasing cone length. Therefore, any particle away from the cyclone wall may be whisked into the outlet gas stream.

### Cyclone Hoppers

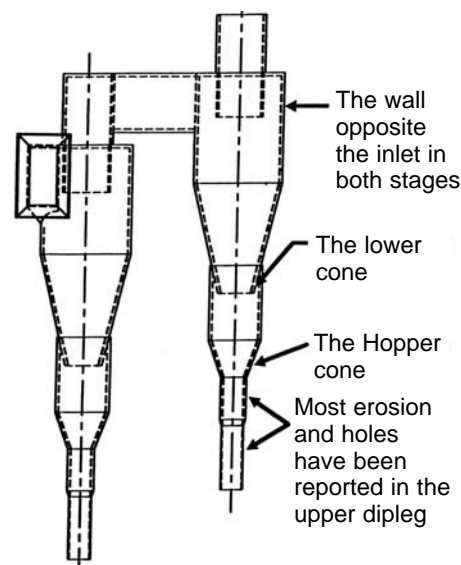
A cyclone hopper is unnecessary only where inlet catalyst loading is very high, such as in a cyclone directly connected to a reactor, and where the total length of the cone and cylinder is four or more times the cyclone cylinder's inside diameter. Otherwise, a cyclone hopper permits catalyst to drop away from the apex of the vortex formed by a gas stream, and to separate from the gas. In actual operation, gas stream vortices move around randomly, such that without a hopper, the moving vortex would intermittently contact catalyst on dipleg walls, thus re-entraining some catalyst eroding dipleg walls, and attriting catalyst into fine particles which become future catalyst losses. Because the ascending gas stream, the descending gas stream, and the descending catalyst stream must pass through the cyclone cone outlet into the hopper, if the catalyst stream flow rate is too great, there will be insufficient cross sectional area for the ascending and descending gas streams to pass, resulting in some of the collected catalyst to be re-entrained in the gas flow and carried out of the cyclone. Empirically re-entrainment of catalyst particles has been found to occur when the weight for catalyst particles rate entering the cyclone divided by the cross sectional area of the cone outlet exceeds 80 pounds/square foot-second. This flow rate is about one half of the recommended maximum flow rate of 150 pounds/square foot-second in a dipleg. While there are published reports in excess of 200 pounds/ square foot-second during laboratory testing, actual operating FCCU catalysts loadings are not constant and the recommended maximum flow rate compensates for operating fluctuations.

### Cyclone Diplegs

Because collected catalyst is returned to the bottom of the vessel through diplegs, each dipleg provides a barometric seal to

prevent or minimize gas leaking from the vessel into the cyclone hopper outlet. Leaking gas would re-entrain collected catalyst particles through a hopper outlet and carry them out of the cyclone with the exiting gas as catalyst losses. Therefore, the maximum catalyst level in dipleg should be a minimum of 2 feet below the hopper/dipleg weld line. Because first-stage cyclone efficiencies are normally greater than 99.9%, the entire amount of catalyst entering the first-stage is used to calculate first-stage dipleg pipe size. Because second-stage dipleg mass flow is normally very low, second-stage dipleg cross section area is typically between ¼ to ½ of the first stage dipleg pipe cross sectional area, which, according to some additional criteria, results in a maximum pipe diameter of between 11 ¾ inch and 12 inch.

*Areas where erosion has frequently been reported*

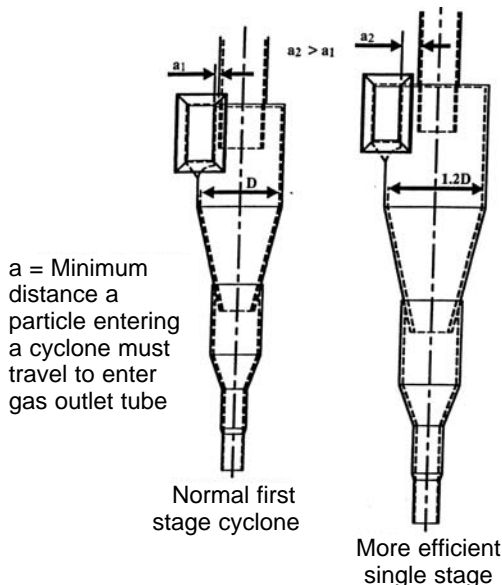


### Dipleg Design

Three basic formulas calculate intermediate pressure drops (1) due to acceleration at the first stage cyclone inlet, (2) from a cyclone inlet to the cyclone gas outlet and (3) from a cyclone inlet to the top of the cyclone dipleg. The two pressure drops from a cyclone inlet to (1) the cyclone gas outlet and (2) the top of the dipleg outlet are not the same and will not be affected the same by any cyclone modification, such as a change in the cyclone gas outlet-tube diameter. No entrance acceleration loss is calculated for cyclones that receive gases and catalyst directly from a riser. Catalyst level in a dipleg is calculated from (1) hopper suction, (2) length of dipleg submerged in the bed, (3) density of fluidized catalyst in the bed and (4) density of fluidized catalyst in the dipleg. See the end of the notebook for all calculations. Most fluidized beds

have densities between 25 pounds/cubic foot and 35 pounds/cubic foot or the bed density, whichever is greater. Because of the high mass flow in first stage diplegs, the typical density is 30 pounds/cubic foot or the bed density, whichever is greater. When the first stage dipleg is not submerged in a bed, a 25 pound/cubic foot density is suggested. For a second stage dipleg, the normal density is 20 pounds/cubic foot to 22 pounds/cubic foot for a new cyclone system and 25 pounds/cubic foot when calculating the ability of an existing system to operate at a higher throughput. In extreme cases, a 25 pound/cubic foot density has been necessary in the design of a replacement cyclone system. The catalyst level above the bed is the sum of (1) any differential in level resulting from different bed and dipleg densities and (2) the pressure drop from the vessel to the top of the dipleg corrected for the difference between water density and the inside-the-dipleg density. The catalyst level above the valve outlet in a dipleg that is not submerged in the bed is only the pressure drop from the vessel to the top of the dipleg corrected for the difference between water density and density from inside the dipleg.

### Comparison of Reactor Cyclones



### Reactor Cyclone Stages

Single stage cyclones, which are used when the riser in a reactor vessel has a discharge device other than a cyclone, are more efficient than the first and second stage cyclones previously used in two stage reactor cyclone systems and currently used in two stage regenerator cyclone

systems. The more efficient cyclones, as compared to the first of the two stage cyclone, have (1) no change in the inlet area, (2) no change or a smaller gas outlet tube diameter, (3) a 20% greater above-the-cone cylinder diameter and (4) a 20% increase of all other dimensions. Because only a single stage of the more efficient cyclone is used, these larger cyclones will fit in a vessel occupied by two-stage cyclones resulting in reduced (1) catalyst carry-over to the fractionator and (2) capital equipment costs. Recently two stage cyclone stems have come back into use where first stage cyclones are connected directly to the first stage cyclone gas outlet, thereby obtaining more rapid separation of gases from catalyst, reducing time that gases spend in reactor vessels and, consequently reducing overcracking products.

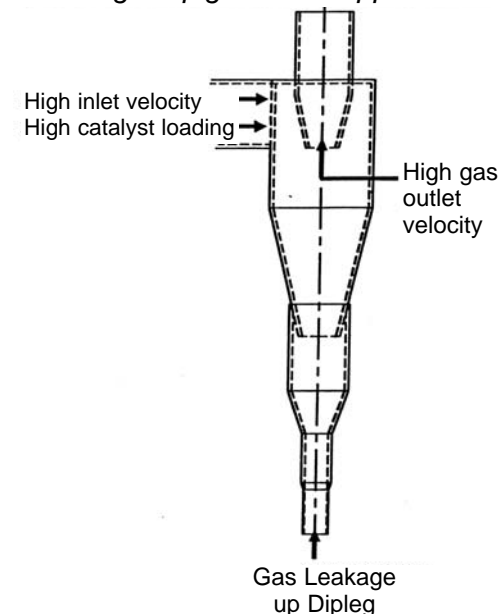
### Cyclone Length Versus Diameter

Typically, cyclones, five years or older, have a 2.5 to 2.7 ratio of inside cyclone length divided by inside cyclone diameter. Erosion in cyclones with ratios about 5.0 is significantly less in longer cones, hoppers, and diplegs. Refiners should discuss cyclone replacement with process licensors and cyclone suppliers, because dipleg length for proper cyclone operation may not be possible with longer second stage cyclones. More efficient first stage cyclones reduce catalyst loading to second stage cyclones. Reduced loading to the second stage cyclone reduces (1) catalyst losses, (2) catalyst attrition and (3) cyclone erosion.

### Second Stage Cyclone Erosion

Descriptions of hoes or extensive erosion in the conical transition portion of second

### Reasons for High Erosion in Second Stage Diplegs and Hoppers

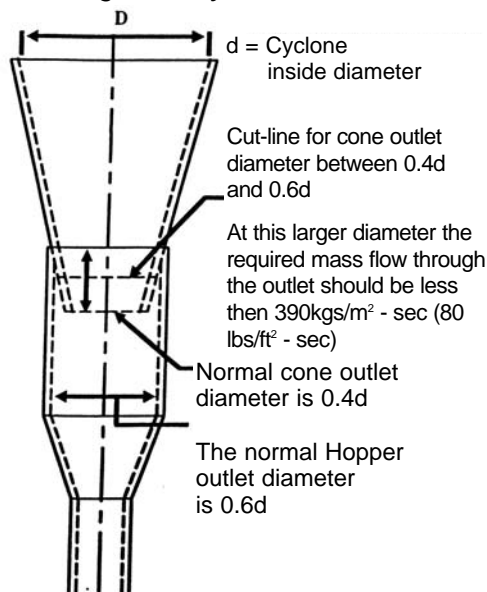


stage hoppers just above diplegs and in the second stage diplegs just below the hoppers cones are common. Erosion in these areas result from one or more of: (1) high second stage cyclone inlet velocities, (2) high second stage cyclone gas outlet gas velocities, (3) excessive gas leakage into and up second stage diplegs and (4) high catalyst carryover to second stage cyclones.

### **High Second Stage Cyclone Inlet Velocities**

Unit operation at conditions higher than those specified for cyclone system design, frequently results in high second stage cyclone gas inlet velocities. Because refractory linings' hardness is equal to or greater than catalyst hardness, catalyst particles are eroding refractory linings at the same time as refractory linings are attriting catalyst particles. Each eroded catalyst particle is broken up into many tiny particles which are returned to the circulating catalyst stream within an FCCU. When these tiny particles are again entrained in FCCU gases, they are carried back into cyclones where, being too small to be collected by any cyclone, they pass through the cyclone with the gas and become part of the catalyst losses.

### **Modification for existing First Stage Cyclones to reduce Mass Flow through the Cyclone Cone Outlet**



### **High Second Stage Cyclone Gas Outlet Tube Velocities**

High gas outlet tube velocities are generally found in second stage regenerator cyclones, where resulting high cyclone pressure drops have little or no effect on downstream operation. Unit operation at

conditions higher than those specified for cyclone system design, frequently results in high second stage cyclone gas outlet tube velocities. However, high outlet tube velocities also commonly occur when second stage cyclones are supplied without inlet scrolls, as a means to lower initial cost without considering operating reliability, future maintenance requirements or long term advantage.

### **Excessive Gas Leakage Into And Up Tractor Second Stage Dipleg**

Before gases enter first stage cyclones, a significant portion of catalyst separates from gases at the riser outlet. Most of the remaining catalyst is collected in first stage cyclones. Because very little catalyst entered second stage cyclones, there is seldom enough collected catalyst in each dipleg to cover the perimeter of a valves seat in a horizontally closing counterweighted valve. Differential pressure across each valve and dipleg, normally about 2.0 psi, can suck a significant amount of gas into the dipleg. Not only does this entering gas carry catalyst into the dipleg, but it also re-entrains some catalyst into the dipleg. When the rising gas meets the spinning vortex of cyclone gases from the top of the dipleg, catalyst particles in the rising gas stream are accelerated by the spinning vortex. These accelerated particles erode the upper portion of the dipleg and the lower portion of the cyclone hopper. Because of this, process licensors now specify single stage cyclones in reactors where the riser discharge provides primary catalyst separation. These single stage cyclones are designed for higher efficiency and higher pressure drop than first stage cyclones in a two stage reactor cyclone system. In most cases, the number of single stage cyclones required is greater than the number of first stage cyclones required.

### **High Catalyst Carryover To Second Stage Cyclones**

The most common cause of high catalyst carryover to second stage cyclones are high catalyst mass flows in the first stage cyclone cones and diplegs. However, cyclone modifications can be made to reduce mass flow through first stage cyclone cones caused by operation at higher than design conditions. Normally, cyclone cone opening diameter is  $2/5$  of the cyclone diameter and the cyclone hopper cylindrical portion diameter is  $3/5$  of the cyclone diameter. See the drawing at the end of this notebook. On most cyclones

supplied within the past 15 years, the cylindrical portion of the cyclone hopper extends up to the cyclone cone putting the portion of the cyclone cone with a diameter of between 2/5 and 3/5 of the cyclone diameter inside the cyclone hopper. Part or all of the portion inside the hopper can be cut off to reduce the mass flow through the cone opening to less than 80 pounds/cubic foot-second. While the efficiency of a cyclone with a cone opening larger than 2/5 of the cyclone diameter will be a little less efficient than the original design, reductions in both catalyst attrition and catalyst re-entrainment will result in significantly reduced catalyst losses.

### High Catalyst Losses

High catalyst losses usually occur as a result of: (1) mechanical failures, (2) catalyst attrition, (3) excessive mass flows in cyclones and diplegs and (4) dipleg length.

### Mechanical Failures

When catalyst losses gradually or suddenly increase, the first thought is usually a mechanical failure. Frequently discussed mechanical failures are (1) leaks at broken welds or high-stress tears, (2) holes formed by erosion in cyclones or diplegs, (3) blockage in diplegs, (4) malfunctioning or damaged dipleg valves, and (5) dipleg valves which do not close because of bent or lost closure plates.

### Catalyst Attrition

In addition to catalyst attrition in cyclones, catalyst attrition also occurs as a result of: (1) improperly designed, eroded or missing orifices in steam lines, (2) excessive velocities in the air grid, (3) high catalyst velocities in slide valves and (4) high turbulence caused by broken air grids.

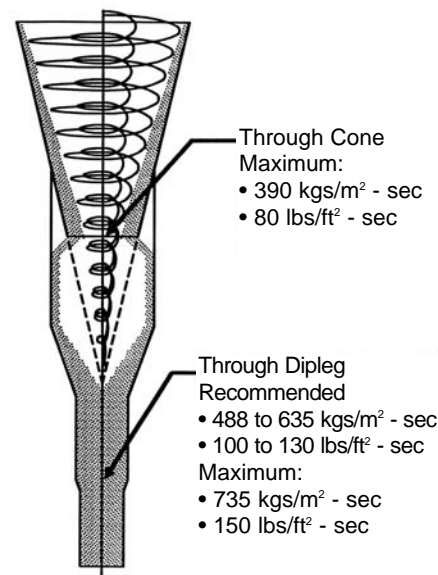
### Excessive Mass Flow In Cyclones And Diplegs

When the quantity of catalyst entering first stage cyclones becomes greater than the maximum amount that will flow down diplegs, usually resulting from increased gas rates to cyclones, catalyst level backs up into the cyclone hoppers until it reaches a level where it is re-entrained by the cyclone gases and carried to the second stage cyclones. Significant catalyst attrition occurs during re-entrainment.

### Insufficient Dipleg Length

While most cyclone systems, when designed, have diplegs which are long enough so that dipleg catalyst level is 24

### Mass flow limits



inches or more below the cyclone hopper dipleg weld line, increases in throughput can raise the required dipleg level to the point where it reaches the cyclone vortex. When this occurs, the results will be both catalyst attrition and cyclone cone and hopper erosion. In addition, some catalyst will be re-entrained in the existing gas stream and carried out of the cyclones. Because the highest catalyst level is normally in the cyclones last stage diplegs, re-entrained catalyst becomes additional losses. High catalyst losses for any reason except catalyst attrition will result in reduction of 0 to 40 micron particles in the equilibrium catalyst. In some FCCUs the effect of this loss of fines on catalyst circulation is more critical than the increased catalyst losses.

### Finding The More Efficient Cyclone Stage

In most two stage cyclone systems both cyclone stage diameters are the same, but the cyclone inlet area of the first stage is greater than that of the second stage. Because the ratio of the cylinder (barrel) cross-sectional area to the cyclone inlet area is greater than that ratio for the first stage, second stage cyclones are more efficient than first stage cyclones. From the time when the first two stage cyclone systems were designed, generally the more efficient cyclones had been in the second stage. However, when negative effects of excessive mass flows through the first stage cyclone became recognized, placement of the most efficient cyclone was questioned. If the more efficient design of the second

# INTRODUCTION TO AIR CLASSIFICATION

stage cyclones was used for the first stage cyclones, the diameter of the first stage would increase to maintain the same inlet area. Correspondingly, the first stage cyclone cone outlet diameter would increase, thus, reducing the mass flow through the cyclone cones. The more efficient cyclones are longer, but this is not a problem because the catalyst level in the first stage diplegs is normally about midway between the hopper dipleg weld line and the catalyst bed. Not only can the first stage diplegs be shortened to accommodate this additional cyclone length, but the diplegs can be further shortened to accommodate an increase in the cyclone length-to-diameter ratio.

## **Actual Catalyst Losses Proven Location**

In considering more efficient cyclones for the first stage, alternative cyclone designs were reviewed for the second stage. Using larger first stage cyclones reduced the plan area available for second stage cyclones, suggesting that second stage cyclones should now be the type used in the first stage. Comparison of performance calculations for the traditional second stage cyclones alternate and smaller second stage cyclones predicted a negligible catalyst loss difference. Further, because the smaller cyclones were shorter, more dipleg length was available, increasing the cyclone length to diameter ratio. When this reverse cyclone design was put into service, the actual catalyst losses were 75% of estimated losses. Because estimated losses were based on actual losses of catalyst fines generated by catalyst attrition in over 100 operating units, the reduction in actual catalyst losses from those estimated suggested that most catalyst attrition had been taking place in the second stage. Consequently, by using more efficient first stage cyclones, catalyst loading to the second stage cyclones was reduced, which in turn significantly reduced catalyst attrition. Three years later inspection found very little erosion in the second stage cyclones and no measurable erosion in the first stage cyclones. Therefore, plans to replace regenerator cyclone systems or a reactor riser upper cyclone system should incorporate more efficient cyclones in the first or riser stage and slightly less efficient cyclones in the second or upper stage. Currently operating units, particularly regenerators with superficial velocities of 3.0 feet/second, have recorded significantly reduced cyclone losses and reduced cyclone maintenance.

The logo for Buell Refinery Cyclones, featuring the word "Buell" in a large, bold, blue, sans-serif font. The letter "l" is stylized with a curved top that loops back to the right. A registered trademark symbol (®) is located to the upper right of the "l".

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