PARTICLE PROFESSOR

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Managing cyclone reliability

Cyclone dust collectors have been in use for at least 150 years and probably even longer than that. A major benefit to using cyclones in commercial operations is that cyclones collect fines without using any moving parts. However, a cyclone's service life tends to be unpredictable and can limit its overall potential. For some applications, cyclones can last decades, but for many others, they are useful for only a few years. Even in fluidized catalytic cracking (FCC) operation, which has been around for 60 years, cyclone reliability can vary by a decade.

Repairs or replacements tend to be costly, mostly due to the downtime that happens during such activities. A 2006 report by Solomon Associates, an energy industry benchmarking company, on the reliability of FCC for petroleum production found that out of all the equipment, the reverse-flow cyclones in the reactors and regenerators were the most likely to cause an unscheduled shutdown or require more than expected repairs during a scheduled shutdown.[1]

In fact, erosion in cyclones was the main reason for this reliability issue. For a well-designed cyclone system encompassing primary and secondary cyclones, erosion appears to be limited to the secondary cyclone's lower bottom region. The higher loadings in a primary cyclone tend to mitigate erosion, provided the outlet tube isn't interacting with the inlet flow. This observation was noted in my last article concerning cyclone design and unobstructed paths.[2]

We can be even more specific about a cyclone's reliability issue. More often than not, the erosion in the secondary cyclone appears to be inherent to the design and best limited by reducing the outlet velocity. However, the best way to increase collection efficiency is to increase the outlet velocity, which is problematic. Indeed, a secondary cyclone's main objective is its collection efficiency. As a result, many secondary cyclones are designed with outlet velocities that are too high to prevent erosion. In other words, there's a trade-off between higher collection efficiency and cyclone reliability with secondary or low-loading cyclones.

Erosion in secondary cyclones stems from the long inner vortex that forms in the secondary cyclone, as discussed in my previous articles.[2, 3] For low-loading cyclones such as secondary cyclones, this inner vortex can extend well into the cone region, as shown in Figure 1. The inner vortex creates a region of fast-moving particles rubbing on the lower cone wall. In some cases, I've seen evidence of this swirling effect extend well into the dipleg. In fact, this type of erosion can impact the dipleg as much as the lower cone region. In one case, I saw the dipleg completely detached from the cyclone at the point where the refractory lining in the dipleg stopped, which was 3 feet below the cyclone exit.

Measuring erosion in secondary cyclones

At Particulate Solid Research Inc. (PSRI), we're interested in mitigating the erosion in secondary cyclones. Using a 17-inch- (43-cm-) diameter secondary cyclone layered with a uniform plastic coating, we were able to measure erosion rates with varying designs and operating conditions.[4] We compared a standard cyclone design with cyclones equipped with different dust hopper types. Some cyclone vendors claim that dust hoppers reduce erosion in secondary cyclones. A cyclone with a dust hopper added to the cyclone's bottom is shown in Figure 2.

We also investigated the efficacy of mitigating erosion by adding a vortex stabilizer to a secondary cyclone. A vortex stabilizer is a plate or conical hat that has an annular (ring-shaped) gap in it and is located one-third of the way up from the cone's bottom, as shown in Figure 3. As the name suggests, a vortex stabilizer stabilizes and contains the vortex within a cyclone to

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FIGURE 1

The inner and outer vortex are inherent to a reverse-flow cyclone but can also cause erosion.

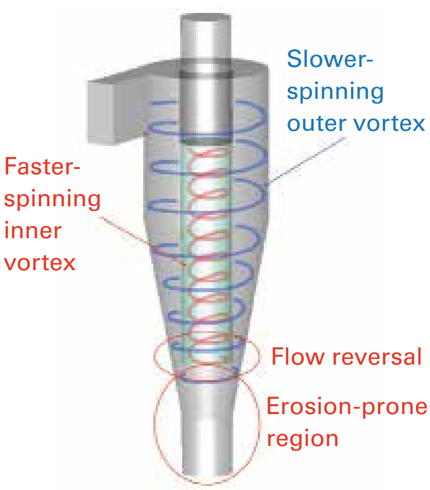


FIGURE 2

An example of a cyclone equipped with a dust hopper.

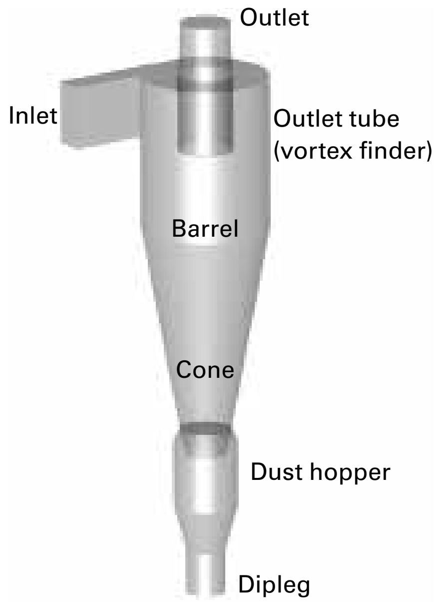
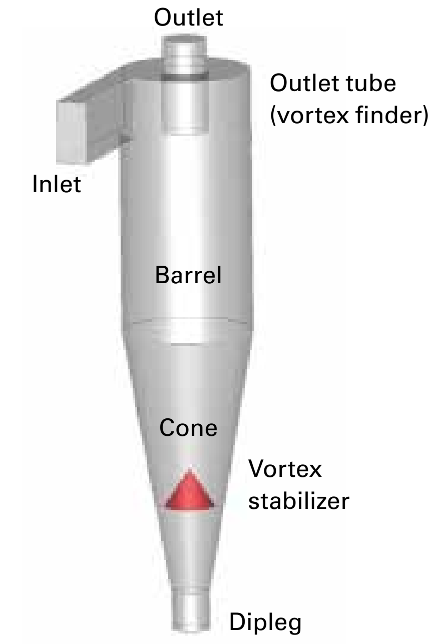


FIGURE 3

A schematic drawing of a cyclone equipped with a vortex stabilizer.



reduce cyclone erosion in the lower cone region.

By weighing the cyclones before and after testing, we were able to quantify the erosion rates of all four cyclones using FCC catalyst fines (Geldart Group A powder) at an inlet velocity of 65 ft/s (20 m/s) and a solids loading of 14 grains/ft^3 (32 g/m^3). We found that the dust hopper addition did reduce the erosion in the cone region by approximately 50 percent, as shown in Figure 4. That means if you have a standard cyclone with a 3-year service life, adding a dust hopper could double that service life to 6 years.

Moreover, we see in Figure 4 that the vortex stabilizer reduced cone erosion by 80 percent. With a vortex stabilizer, cyclone service life could be extended from 3 to 15 years. What's even more interesting is that the vortex stabilizer is nothing new. Vortex stabilizers had some applications in combustors back in the 1960s. In the early 1990s, vortex stabilizers found applications in FCC operations, and many of those cyclones are still in service today.

Reducing erosion with vortex stabilizers

As previously mentioned, a vortex stabilizer is typically a conical hat located one-third of the way up from the cyclone cone's bottom. The vortex stabilizer has an annular gap that should be a little wider than the typical objects that may have to pass through the cyclone, such as coke debris and refractory tiles for example. For most high-temperature applications, this would be the size of the refractory tile used to protect the cyclone's interior. A schematic drawing of a vortex stabilizer in a cyclone with a cyclone length-to-barrel diameter (L/D_b) of 5 is shown in Figure 3.

To further understand the benefits of vortex stabilizers, we investigated the outlet gas velocity's impact on erosion for cyclones with and without a vortex stabilizer. The results of erosion testing with the 17-inch- (43-cm-) diameter cyclones at increasing outlet gas velocities is shown in Figure 5. As previously noted, increasing the outlet velocity can significantly impact the erosion of the cyclone's cone region — and perhaps the dipleg, too. Going from 50 to 125 ft/s (15 to 38 m/s) doubled the erosion rate in a cyclone without a vortex stabilizer, as shown in Figure 5.

However, our experiments indicate that by adding a vortex stabilizer to the same cyclone, one can reduce the erosion rate at low and even high outlet gas velocities, with the reduction being most dramatic at high gas velocity. This is significant. Figure 5 suggests that using a higher outlet gas velocity to better the cyclone's collection efficiency may no longer need to be balanced against a shortened cyclone service life (although higher velocity with downstream components may be an issue and would need to be checked). This reduced-erosion

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benefit with the vortex stabilizer isn't observed with a dust hopper attached to the cyclone though.

Cyclone hydrodynamics and vortex stabilizers

To better evaluate the performance of secondary cyclones with vortex stabilizers, we used a computational fluid dynamic (CFD) code to model the gas and solids hydrodynamics. The code is Barracuda VR from CPFD Software and uses the multiphase particle-in-cell (MP-PIC) approach to model the particles. This approach allows us to model the entire particle size distribution and not just one representative particle size.[5]

The results of our CFD model for the 17-inch- (43-cm-) diameter cyclones under conditions similar to our experimental work are shown in Figure 6. The CFD model suggests that the hydrodynamics in the region above the vortex stabilizer resemble the hydrodynamics in the same region for the cyclone without the vortex stabilizer. By contrast, the hydrodynamics for the two cyclones differ significantly in the lower cyclone region. The model shows a diminished angular and circumferential flow of gas and solids in the lower cone region for the cyclone with the vortex stabilizer. As erosion is usually a function of the impact velocity to the power squared or cubed,[6] small changes in the impact velocity can dramatically alter the erosion rate. Our CFD model demonstrates that the vortex stabilizer does just that; it reduces the angular velocity. This, in turn, reduces the impact velocity in the bottom cone region when a vortex stabilizer is present.

Figure 7 shows these two cyclone scenarios in practice. The cyclone without the vortex stabilizer shows multiple ropings of particles swirling downward in the lower cyclone cone region and dipleg. The associated high kinetic energy is likely the culprit for promoting erosion in this region. In the cyclone with the vortex stabilizer, these high-kinetic-energy particle ropes were quickly dissipated once they reached the vortex stabilizer. The angular motion below the vortex stabilizer has shifted more toward axial motion, reducing the impact velocity at the wall.

Thus, PSRI data and models, along with commercial experience, suggest that vortex stabilizers may be an effective solution for significantly reducing erosion in secondary or low-loading cyclones. However, what does the vortex stabilizer do to the collection efficiency and cyclone pressure drop?

FIGURE 4

Erosion rate study for four 17-inch- (43-cm-) diameter cyclones using FCC catalyst fines at an inlet gas velocity of 65 ft/s (20 m/s) and a solids loading of 14 grains/ft³ (32 g/m³) with an L/D_b of 5 for the cyclone size.

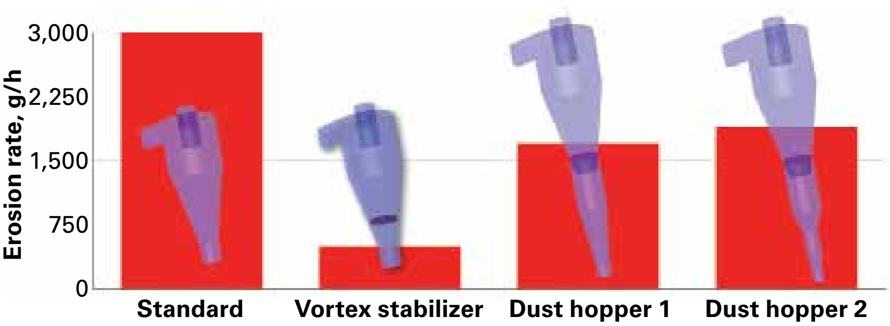

FIGURE 5

Erosion rate study with increasing outlet gas velocity for two 17-inch- (43-cm-) diameter cyclones with and without vortex stabilizers using FCC fines at an inlet gas velocity of 65 ft/s (20 m/s) and a solids loading of 14 grains/ft³ (32 g/m³) with a L/D_b of 5 for the cyclone size.

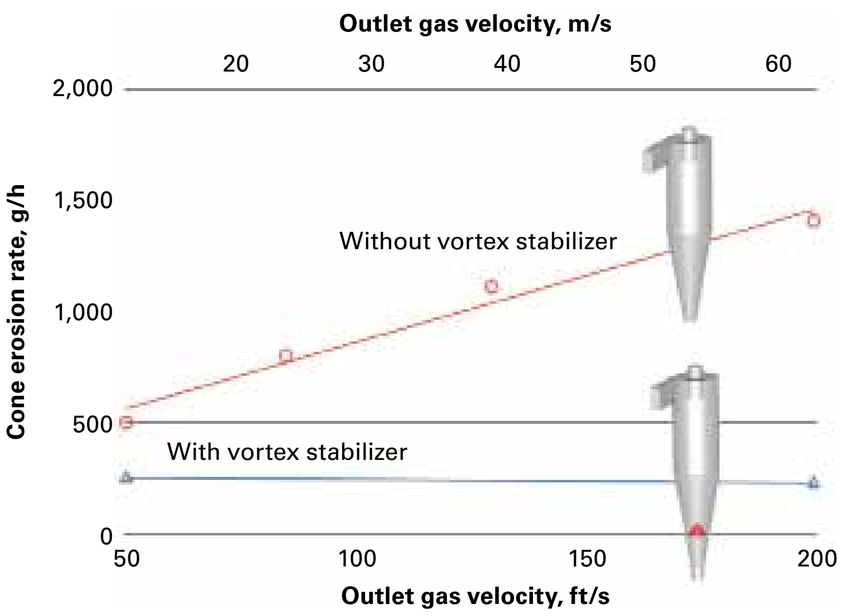

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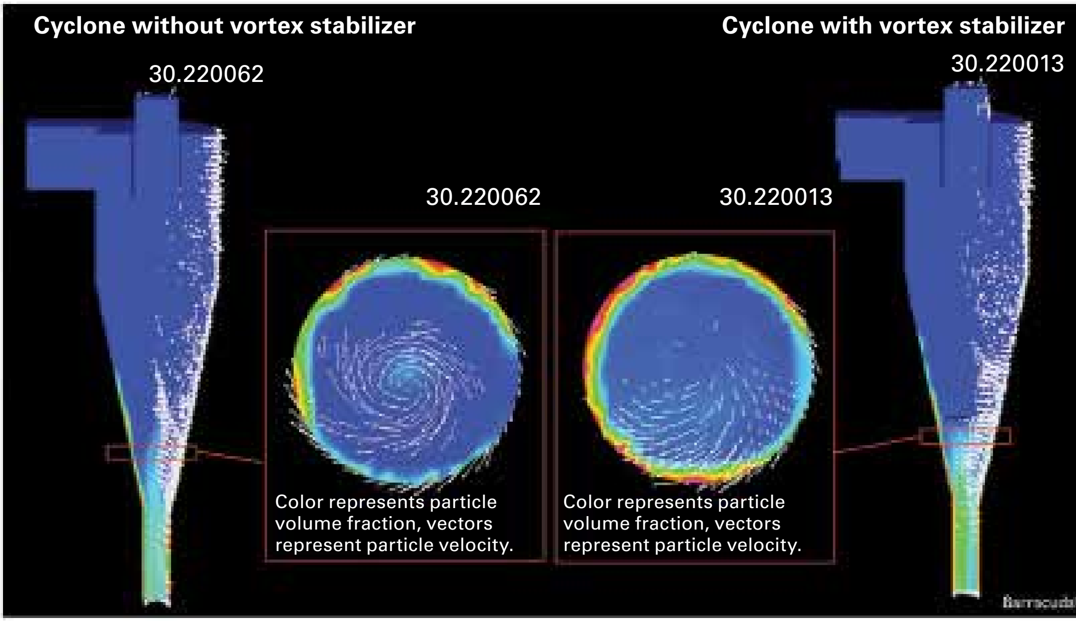
FIGURE 6

A CFD study of 17-inch- (43-cm-) diameter cyclones with and without a vortex stabilizer using FCC catalyst fines at an inlet gas velocity of 65 ft/s (20 m/s) and a solids loading of 14 grains/ft^3 (32 g/m^3) with a L/D_b of 5 for the cyclone size. Color is an indication of solids concentration with blue being the lowest and red the highest.



Impact on collection efficiency

PSRI addressed the issue of a cyclone's efficiency when a vortex stabilizer is added. Using the same 17-inch- (43-cm-) diameter cyclones, now without the layered plastered coating, we measured the collection efficiency for FCC catalyst fines (with a d_{p50} of 27 microns) with and without the vortex stabilizers. The findings of that study where the overall cyclone efficiency is compared to various cyclone sizes (e.g., L/D_b of 3 and 5) are shown in Figure 8.

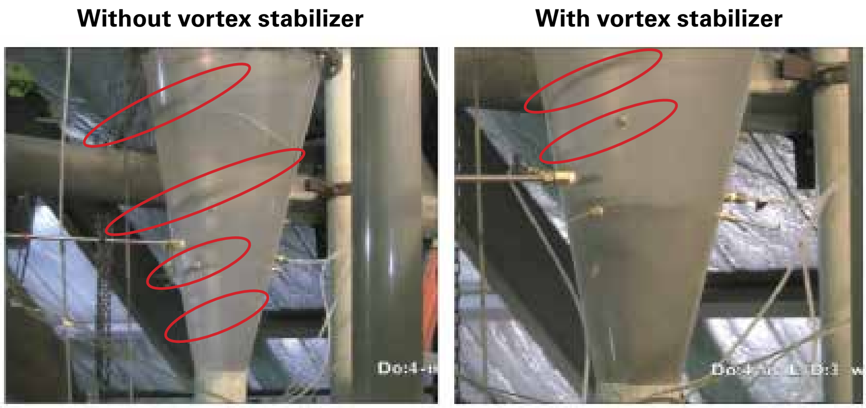
For the most part, using a vortex stabilizer in a cyclone resulted in an average 0.2 percent decrease in the overall particle collection efficiency. That may sound small, but in the world of cyclones, even a 0.2 percent decrease in efficiency is potentially concerning.

However, as shown in Figure 5, the addition of a vortex stabilizer desensitizes the erosion rate from the outlet gas velocity, which impacts collection efficiency. Stated another way, a cyclone with a vortex stabilizer may be able to operate at a higher outlet gas velocity without suffering strong consequences from erosion in the lower cone region. Thus, increasing the outlet gas velocity could rectify the collection efficiency issue and may even exceed the cyclone's efficiency without the vortex stabilizer while the impact on erosion in the cone region continues to be mitigated.

For new cyclones, the fear of erosion in the cyclone cone region and dipleg shouldn't limit your design needs. In other words, the rule of thumb that outlet velocities should be less than approximately 100 ft/s (30 m/s) no longer applies. Retrofitting existing cyclones

FIGURE 7

Photos of solids roping and swirling for 17-inch- (43-cm-) diameter cyclones with and without a vortex stabilizer using FCC catalyst fines at an inlet gas velocity of 65 ft/s (20 m/s) and a solids loading of 14 grains/ft^3 (32 g/m^3) with a L/D_b of 5 for the cyclone size.



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with an inlet or outlet insert and a vortex stabilizer, for example, is a little more involved. However, such modification no longer involves the consideration of lengthening the dipleg.

Impact on pressure drop

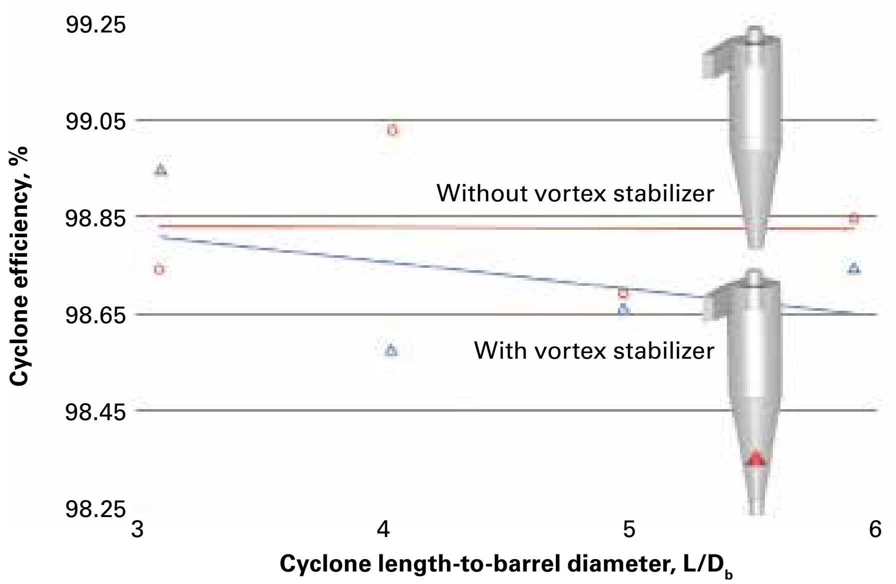
The next question for us to address was if the vortex stabilizer affected the cyclone pressure drop. Cyclone pressure drop is a crucial design parameter because the dipleg length needs to account for the pressure drop through the fluidized bed and in the primary and secondary cyclones (this is more involved for circulating fluidized beds). An increase in the secondary cyclone pressure drop could result in the need for a longer dipleg, which isn't easy to install in most cases.

Using the same 17-inch- (43-cm-) diameter cyclones, we measured the pressure drop across various regions of the cyclones during operation. The results were interesting. We did see the pressure drop increase by about 10 percent, going from the inlet to the secondary cyclone outlet when the cyclone was equipped with a vortex stabilizer. This increase in pressure drop could affect downstream equipment. However, we saw the opposite effect when comparing the pressure drop from the inlet to the dipleg in the same cyclone. For this metric, the cyclone with the vortex stabilizer had a lower pressure drop across the inlet to the dipleg than the cyclone without the vortex stabilizer.

This lower pressure drop from the inlet to the dipleg means that for a cyclone with a vortex stabilizer, a shorter dipleg can be used. The results of this pressure drop comparison in terms of the solids height in the dipleg for two different sized cyclones (each with and without a vortex stabilizer) are shown in Figure 9. For both

FIGURE 8

Overall collection efficiency with increasing cyclone length (L/D_b) for 17-inch- (43-cm-) diameter cyclones with and without vortex stabilizers using FCC fines at an inlet gas velocity of 65 ft/s (20 m/s) and a solids loading of 14 grains/ft³ (32 g/m³).



cyclones with the vortex stabilizer, the bed height in the dipleg was only 40 to 50 percent of the bed height for the cyclones without a vortex stabilizer. These results suggest that retrofitting a cyclone to include a vortex stabilizer can be readily accomplished, as modifications to an existing dipleg may not be needed.

Summary

Erosion in cyclones typically happens in the upper barrel region and outlet tube of a primary cyclone and in the lower cone region of a secondary cyclone. A good primary cyclone design can mitigate erosion in the upper barrel and outlet tube region. However, erosion in the secondary cyclone is inherent to the solids and air physics and tends to be much more significant.

Fortunately, there are ways to reduce erosion in secondary or low-loading cyclones. Dust hoppers have been used for decades, and PSRI research suggests a dust hopper could double a cyclone's service life. However, a cyclone equipped with a vortex stabilizer may see its service life increase by 5 times the life of a cyclone without a vortex stabilizer.

A vortex stabilizer reduces the swirling flow of solids at the lower cone region wall, which reduces erosion in this area. Some cyclones with vortex stabilizers have been in service for more than 25 years in large commercial applications.

There are precautions to consider when deciding whether to add a vortex stabilizer to your secondary or low-loading cyclone. There may be a decrease in the collection efficiency if modifications aren't made to increase the cyclone's gas outlet velocity. There will be an increase in the pressure drop from the inlet to the outlet of the cyclone, which could impact downstream operations. However, adding a vortex stabilizer won't increase the dipleg height requirement compared to the existing cyclone design without the vortex stabilizer. **PBE**

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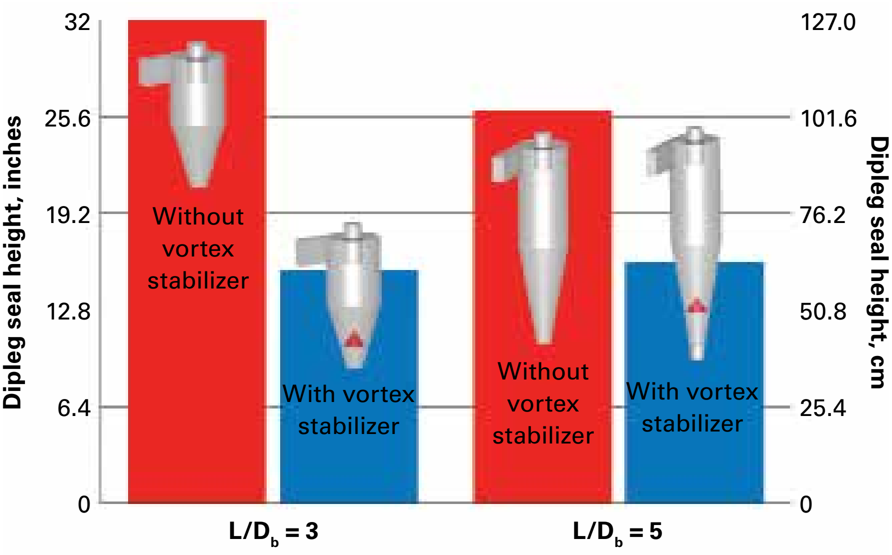
FIGURE 9

Height of solids in dipleg of a short ($L/D_b = 3$) cyclone and a tall ($L/D_b = 5$) cyclone both with and without a vortex stabilizer using FCC fines at an inlet gas velocity of 65 ft/s (20 m/s) and a solids loading of 14 grains/ft^3 (32 g/m^3).



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