





One of Grace's most frequently requested articles, Raymond W. Mott's "Troubleshooting FCC Standpipe Flow Problems," has withstood the test of time. It was originally published in *Catalagram* No. 83 in 1992, and later republished in *Catalagram* No. 106 in 2009. This classic article reviews common symptoms and causes of FCC standpipe flow problems and clearly explains how these problems should be systematically diagnosed. While significant improvements have been made in areas such as advanced process control, modeling, and digitalization since the original print of this article, troubleshooting standpipe flow issues remains one of the most difficult challenges that an FCC operator can face. With larger FCC units being designed and coming online in the coming years, we expect FCC standpipe flow problems to remain a very relevant topic. Grace's experienced technical service representatives are very familiar with standpipe flow issues and troubleshooting, and they can help get your standpipes flowing smoothly again.



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Trouble-Shooting FCC Standpipe Flow Problems

 **Raymond W. Mott**

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Troubleshooting the performance of an ill-behaved FCC standpipe can present one of the most difficult challenges that the FCC process engineer faces. Not only is the nature of the catalyst circulation problem very nebulous, but the existence of a catalyst circulation problem places a great deal of technical and economic pressure on the process engineer's shoulders.

This paper will discuss how to systematically diagnose the operation of an FCC standpipe with chronic problems. In the process, some of the causes for the behaviors observed in standpipe operation will be investigated, and some engineering bench marks against which the operation of the FCC standpipe can be compared will be presented.

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Symptoms of Standpipe Flow Problems

There are a whole range of catalyst circulation symptoms that show up in FCC standpipes. Many of these symptoms are interrelated, and there are several distinctly different problems that exhibit the same symptoms. All of this makes troubleshooting standpipe flow problems extremely challenging.

Some of the symptoms of catalyst circulation problems that commonly occur in standpipes include:

- Low slide valve (or plug valve) differential pressure.
- An inability to circulate additional catalyst despite changes in slide valve position. Often this is accompanied by an inability to control reactor temperature.
- Erratic slide valve differential pressure that threatens the loss of catalyst circulation.
- Physical bouncing or hopping of catalyst standpipes.

Any of these symptoms can make smooth FCC operations impossible. However, before we dive into trouble shooting, it is worth looking into the detailed mechanics of catalyst flow in standpipes to establish a framework for investigation.

Pressure Profiles in the FCC Standpipe

One way to glimpse into the workings of the FCC standpipe is to conduct a pressure survey along its length. Usually, the most readily available way to do this is to conduct a single gauge survey. In this type of survey, a single calibrated pressure gauge is carried up and down the FCC structure to measure the pressure at various locations along the length of the vessels and standpipes. This helps reduce the errors that reading many separate gauges would introduce.

In principle, the FCC standpipe is expected to behave analogously to a pipe full of water. The pressure measured at any depth in the standpipe should be roughly proportional to the density of the fluidized catalyst and the height of the catalyst above the point where the pressure is being measured. Figure 1 shows the “idealized” pressure profile that would be observed in a perfectly behaved FCC standpipe. The pressure is linearly increasing with respect to depth in the standpipe.

In practice, when a standpipe is experiencing operating difficulty, the pressures observed at any point along the length of the standpipe may be going through wild gyrations. So, taking a meaningful single gauge pressure survey will require patience.

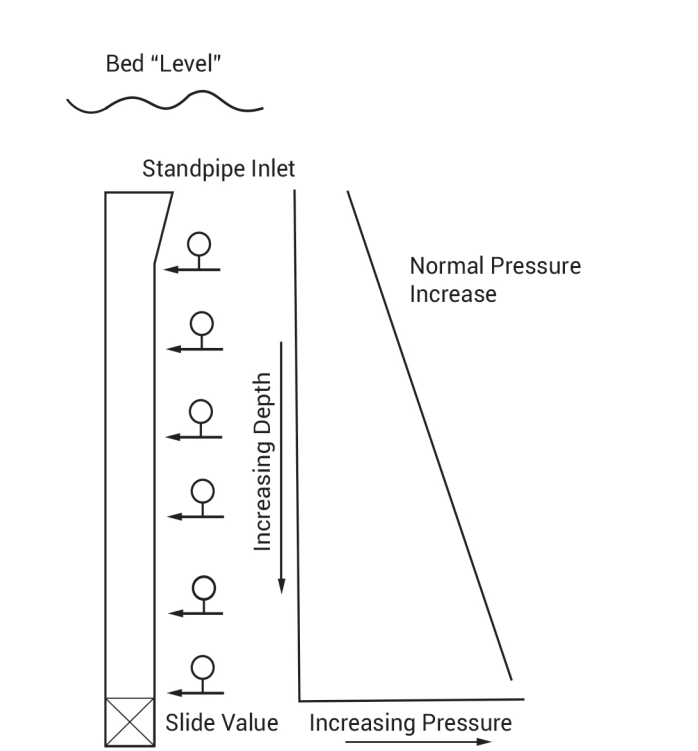


Figure 1. Idealized Pressure Profile in a Standpipe

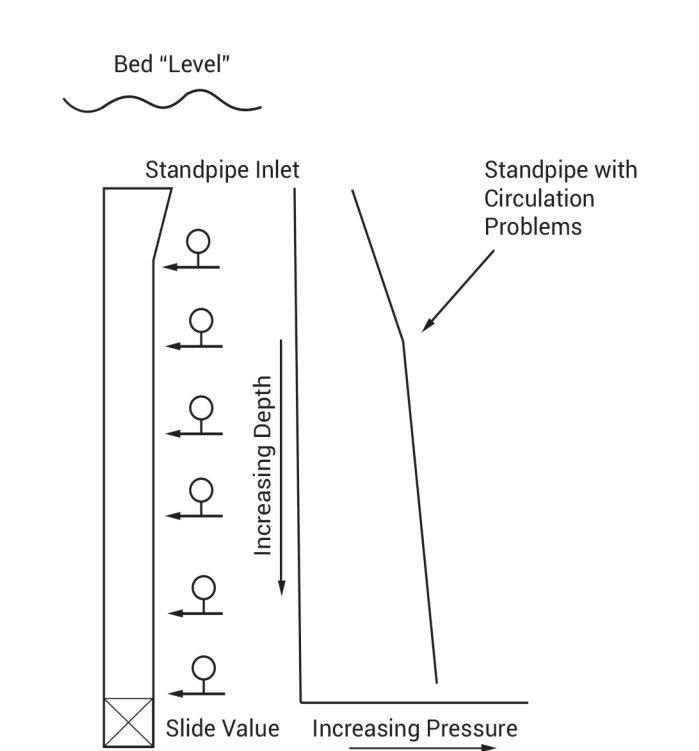


Figure 2. Idealized Pressure Profile in a Standpipe

Obviously, FCC catalyst differs from water in the important sense that it is actually a fluidized solid. Less obvious is the fact that non-fluidized powders can support their own weight against the walls of their container. For example, as an empty storage silo is filled with corn or wheat, the pressure on the floor of the silo initially increases as the height of grain in the silo increases. However, when the grain reaches a depth of approximately three times the diameter of the silo, the pressure on the floor of the silo stops increasing. The grain in the upper levels of the silo supports most of its own weight against the silo walls instead of the floor!

The implications for FCC catalyst flow in a standpipe are dramatic. If the catalyst loses its fluidization, it, too can start supporting a portion of its weight against the standpipe walls, and the slide valve at the bottom of the standpipe will see a reduced pressure buildup. A pressure survey will provide a better idea of what is going on inside the standpipe, and may help isolate where such local problems as defluidization are occurring.

Figure 2 shows the pressure profile for a standpipe that is experiencing moderate circulation difficulties. At first, the pressure is increasing normally as you descend the standpipe; however, this standpipe has trouble building additional pressure below the second aeration tap (counting from the top down).

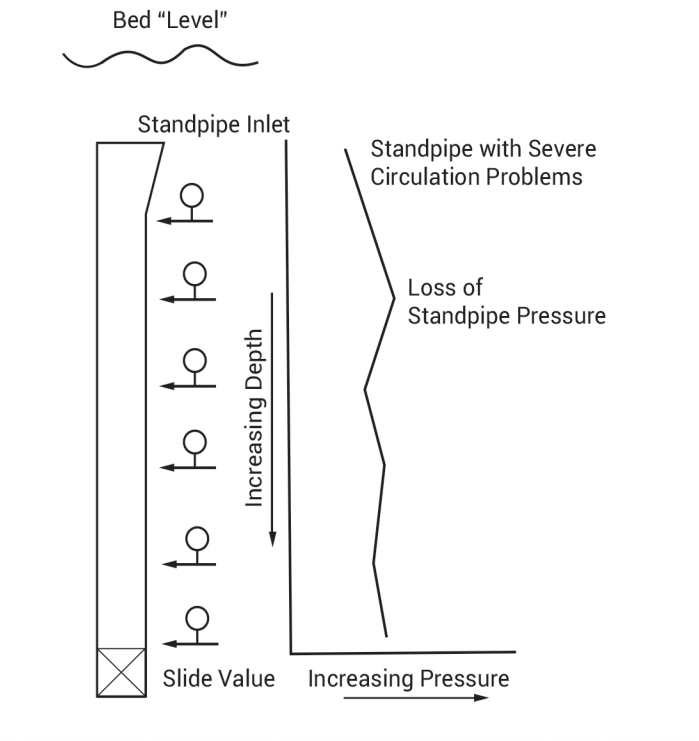


Figure 3. Idealized Pressure Profile in a Standpipe

A more extreme problem is shown in Figure 3. In this standpipe, the pressure profile actually shows a loss of pressure below the second aeration tap, and an inability to build up much pressure below this point.

The single gauge pressure surveys shown in Figures 2 and 3 suggest that the catalyst flow may be obstructed by a foreign object or by bubbles. Another possibility is that the catalyst may be losing its fluidization in some sections of the standpipe so that a portion of the catalyst weight is supported against the walls.

The Narrow Operating Window of the FCC Catalyst

FCC catalyst only has a narrow range of conditions under which it will flow well in standpipes. At one end of this operating range, the catalyst is at the point of incipient bubbling. If any more gas were present in the fluidized catalyst emulsion, then there would be a tendency for the system to generate bubbles. In standpipes, bubble formation tends to impede catalyst flow because the bubbles act as obstacles that the catalyst must flow around.

Incipient fluidization represents the other end of the well-behaved operating spectrum. If there were any less gas present in the catalyst emulsion at this point, the fluidized catalyst would then revert back to a packed bed.

These two extremes of fluidization are often measured in terms of velocity, and many articles have been written on measuring the superficial gas velocity at incipient bubbling (U_{ib}) and the superficial gas velocity at incipient fluidization (U_{if}) in beds of FCC catalyst. In an operating FCC standpipe, however, gas velocity has only a very nebulous meaning because it is difficult to determine what the relevant gas velocity is.

Fortunately, the well-behaved operating range can also be defined in terms of the density of the fluidized emulsion. Thus, the range of densities between the density of the emulsion at its point of incipient fluidization (ρ_{if}), and its point of incipient bubbling (ρ_{ib}) can be considered the range of densities over which a fluidized FCC catalyst will be well-behaved in a standpipe.

The catalyst beds encountered in commercial FCC units do not generally operate as quiescent fluidized beds that are confined to operate within the range of densities mentioned above. The typical catalyst bed found in the average FCC regenerator, for example, is usually operating as a very active bubbling bed. In open fluidized beds, bubbles do not present a fluidization problem. However, in a standpipe, bubbles need to be avoided. Thus, as the bubbling bed of catalyst begins to enter an FCC standpipe, it needs to shed itself of the excess gas bubbles to avoid dragging them down into the standpipe. The standpipe

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inlet geometry and location of the standpipe inlets should be carefully designed to allow this initial shedding of excess gas to take place in an orderly fashion.

It is beyond the scope of this paper to go into how the specific inlet geometry should be arranged; however, from the troubleshooting point of view, the process engineer needs to be aware that this process of shedding excess gas is taking place at the inlet to the standpipe. Thus, introducing aeration right at the standpipe inlet often causes more problems than it solves.

The Compression of Catalyst in a Standpipe

After the fluidized FCC catalyst emulsion enters the top of the standpipe and begins its descent, it starts to undergo a form of compression. As the catalyst descends the standpipe, the pressure head that is seen at any given depth in the standpipe increases. This increasing pressure compresses the interstitial gas that is surrounding the catalyst particles, as well as the gas that is in the pores of the catalyst particles. The net result of all this gas compression, is that the volume of the fluidizing gas surrounding the catalyst particles is reduced. So the catalyst particles move closer together, and the density of the emulsion increases.

If the standpipe is long enough, and if no aeration is introduced along the length of the standpipe, then this process of compression will continue as the catalyst travels deeper and deeper into the standpipe. This will cause the density of the catalyst emulsion to continue to increase until the catalyst emulsion reaches its incipient fluidization density. If the catalyst emulsion is compressed past this point, the emulsion will change phase from a fluidized bed to a packed bed, and the catalyst will have trouble circulating.

On FCC units that use standpipe aeration, the purpose of the standpipe aeration is to supply just enough additional gas to the catalyst as it passes each aeration tap to restore the catalyst emulsion to its original volume, as in Figure 4.

The ration of ρ_{if}/ρ_{ib} is known as the “Stable Expansion Ratio” for a fluidized catalyst. The higher this ratio, the more forgiving the fluidized catalyst is to changes in density, and the more easily it will tend to circulate in an FCC unit.

Another way of interpreting this ratio is to realize that it represents the maximum compression factor that the catalyst emulsion can be expected to tolerate as it descends the standpipe before losing its fluidization.

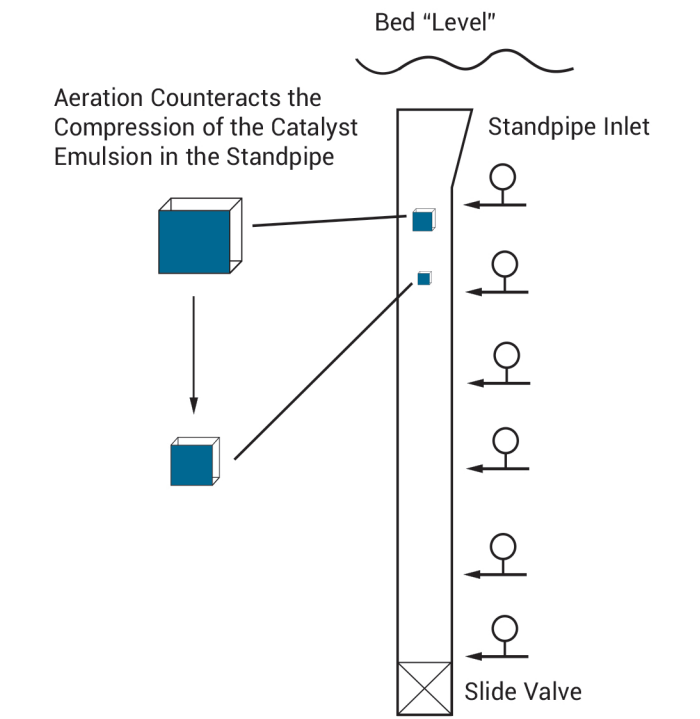


Figure 4. Compression of Catalyst in a Standpipe

Abrahamsen and Geldart¹ have shown that the ratio of the superficial gas velocity at incipient bubbling to the superficial gas velocity at incipient fluidization is a function of the physical properties of the catalyst as shown below.

$$\frac{U_{ib}}{U_{if}} = \frac{2300 \rho_g^{0.126} \mu^{0.523} e^{(0.716 \cdot F)}}{d_p^{0.8} g^{0.934} (\rho_p - \rho_g)^{0.934}} \quad (1)$$

Where:

U_{if} =Superficial Gas Velocity at Incipient Fluidization, m/sec.

U_{ib} =Superficial Gas Velocity at Incipient Bubbling, m/sec.

ρ_g =Gas Density, kg/m³

ρ_p =Particle Density, kg/m³

μ =Gas Viscosity, kg/m sec.

F =0-45 micron Fines Fraction in Catalyst

d_p =Mean Particle Diameter, meters

g =Gravitational Constant, 9.81m/sec²

They also show that the Maximum Stable Expansion Ratio (MSER) can be estimated from the equation below:

$$MSER = \frac{\rho_{if}}{\rho_{ib}} = \left(\frac{U_{ib}}{U_{if}} \right) \quad (2)$$

Inspection of Equations 1 and 2 shows the following:

- Very low fines content in the equilibrium catalyst greatly reduces the maximum stable expansion ratio. Thus, standpipes that normally operate well will often fail when the cyclone performance deteriorates and the 0-40 micron fines content of the equilibrium catalyst falls.
- Catalyst with a very high equilibrium apparent bulk density (ABD) also can aggravate standpipe circulation problems because the maximum stable expansion ratio decreases with increasing catalyst particle density¹.

Both of these effects are clearly illustrated in Figure 5 which is taken from work published by Magnussun². Figure 5 shows the measured Maximum Stable Expansion Ratios for a series of equilibrium FCC catalysts at room temperature and pressure. The sensitivity of the measured MSER in Figure 5 to changes in ABD and the 0-40 micron fines fraction appears to be significantly greater than what Equation 2 would predict. This lack of precise agreement is common in the field of fluidization. It is mentioned here to illustrate that published correlations and measurements need to be applied cautiously.

Equation 2 and Figure 5 both provide estimates of the MSER for FCC catalyst under “ideal” conditions. In actual practice, the effective MSER of the catalyst in the FCC standpipe appears to be only a fraction of this estimated number, so the MSER should not be taken at full face value when looking at standpipe compression. However, the relative changes predicted in MSER by Equation 2 and Figure 5 due to particle size, ABD, viscosity, and gas density are very real effects. It is these relative movements in MSER that are very useful for troubleshooting.

Trouble-Shooting FCC Standpipe Flow Problems

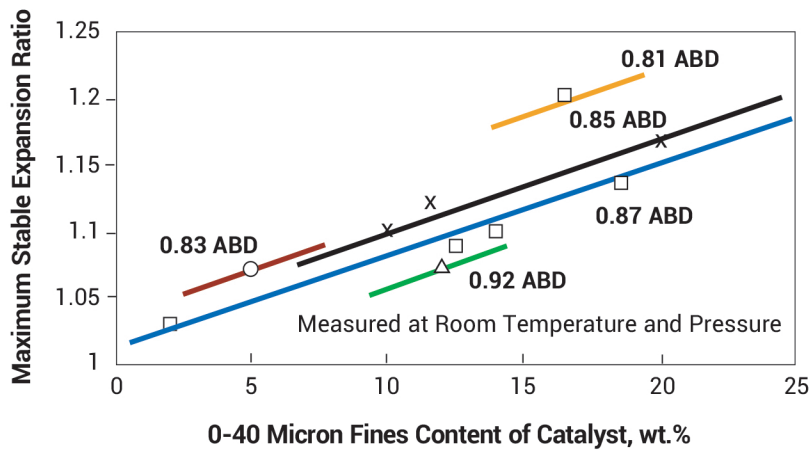


Figure 5. Maximum Stable Expansion Ratio Versus Fines Content of Equilibrium Catalyst

In an operating FCC unit, one of the ramifications of Equations 2 and Figure 5 is that the ability of the equilibrium catalyst to tolerate compression can change dramatically due to subtle effects like a loss of fines, or an increase in ABD that might accompany a catalyst change out.

The limited ability of equilibrium FCC catalyst to tolerate compression places a great deal of importance on proper standpipe design and aeration practices.

With these ideas in mind, let's move on to troubleshooting standpipe circulation problems.

Assess the Situation; Gather Facts and Figures

When troubleshooting, a good way to get started is to gather some facts about the status of the standpipe's operation for comparison against useful bench marks. In the process, ask as many questions as possible about the history, and recent operation of the troubled standpipe. Some of the typical avenues of investigation are outlined below.

Catalyst Flux

A quick calculation of the catalyst flux passing through the standpipe will help indicate how high the duty of the

standpipe is. Calculate the catalyst flux rate (kg/m² second) at which the standpipe is operating.

How does this compare with past operating experience for the unit in question? Many FCC standpipes will operate with a flux as high as 980- 1220 kg/m² second (200-250 lbs/ft² sec). Some standpipes have been observed operating as high as 1465 kg/m² second (300 lbs/ft² sec). If your catalyst flux is up at these levels you may be operating near the practical capacity of your FCC standpipe. If, on the other hand, the catalyst flux is significantly lower than this, then it is likely that something other than a sheer capacity limitation is causing the catalyst circulation problem.

Look at the Standpipe Pressure Profile

Conduct a single gauge pressure survey along the length of the standpipe and the vessel from which it is coming. What type of pressure profile is the standpipe generating? How does this compare with the idealized profiles discussed earlier? Usually, you are looking for a section of standpipe that is not generating the expected pressure head as a clue to where the problem is located.

Sometimes it is difficult to visualize what is going on inside those sections

²Unlike the gas contained in the continuous emulsion phase, bubbles can arise at velocities that are competitive with the velocity of the descending catalyst emulsion in the standpipe. Thus, if bubbles form in the FCC standpipe, they can rise against the flowing catalyst, be pulled down by the flowing catalyst, or remain stationary in the standpipe, depending on the relative bubble and catalyst emulsion velocities involved.

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of the standpipe that are not building pressure. There are really several different phenomena that can create this type of pressure profile.

- The catalyst might be defluidized so that it is supporting its weight against the walls.
- There may be stationary bubbles² in the standpipe that are acting as obstructions.
- There may be a real obstruction like a piece of dropped refractory or a workman's shovel.

In any case, the section of the standpipe immediately below an obstruction will have a tendency to operate with a dilute rain of catalyst falling through an essentially empty standpipe. This type of flow does not generate the pressure buildup that the standpipe needs to produce.

Check the Standpipe Aeration Practices

The aeration rates being used on the standpipes should be checked against the theoretical aeration rates calculated in the next section. Defluidization of the catalyst from under-aeration, or obstructions in the form of bubbles from over-aeration, can both be caused by errors in the standpipe aeration. Unfortunately the symptoms for both these problems are very similar, so it is necessary to use a theoretical aeration rate as a point of reference.

It is very important to calculate the aeration required by each individual aeration tap location along the length of the standpipe. This information provides a great deal of insight into how the standpipe wants to operate, and provides a basis for comparing the actual aeration rates. Not calculating the individual aeration tap requirements is a serious mistake because the opportunity to look at the operating requirements for each section of the standpipe may be missed.

Also, ask as many questions as possible about the standpipe aeration. Some questions that come to mind are:

- How much aeration is being used in the standpipe?
- Is steam, air, or some other gas being used for aeration? Why is this particular media being used?
- If the standpipe is being aerated with steam, is it absolutely dry steam, or could there be condensate slugging into the standpipe?
- How much aeration is being supplied to each individual tap?
- How does the aeration rate compare with the theoretical aeration rate calculated for each individual tap?
- Could some of the aeration taps be plugged?

- How is the aeration being distributed to the taps?
- Does the aeration system use rotometers for each tap, or are orifices being used to obtain distribution?
- How confident are you that the aeration is going where you think it is going?
- How does the aeration rate compare with theoretical and historical bench marks? (More on these later.)
- Are the aeration tap locations correct? Don't automatically assume that they are. (More on this later also.)

If the standpipe does not have aeration, read on, since this is where the plot thickens.

Calculation of Standpipe Aeration Requirements

The calculation of the aeration, needed at any one of the pressure taps, is relatively straightforward. The steps required are outlined below, followed by a worked example.

1. Calculate the volume of catalyst that is descending the standpipe.
2. Calculate the volume of voids that are circulated with the catalyst³.
3. Calculate the absolute pressure that should be observed at the stand-pipe inlet and at the various aeration taps along the standpipe length using an assumed emulsion density.
4. Calculate the change in gas volume due to the pressure increase between adjacent aeration taps.

This is the theoretical volume of gas that should be introduced into the tap under investigation. However, in practice only about 60-70% of this quantity of aeration is usually needed.

The example discussed below is illustrated in Figure 6.

Example 1

Calculate the steam required to aerate the first aeration tap in a regenerator standpipe that is operating at the following conditions:

Catalyst circulation:
12 metric tons per minute

Regenerator Temperature:
682°C (1260°F)

Regenerator Dilute Pressure:
82.7 kPa gauge (12 Psig)

Molecular Weight of Aeration Gas:
18.0 (Steam)

The distance from the surface of the catalyst bed in the regenerator vessel to the inlet of the standpipe is 1.83 meters (6 feet).

The distance from the inlet of the standpipe to the first aeration tap below the inlet is 2.85 meters (9.35 Ft).

You will need to assume a density for the fluidized catalyst inside the standpipe. For the sake of these calculations, it is customary to assume a density of 560.65 kg/m³ (35 lbs/ft³).

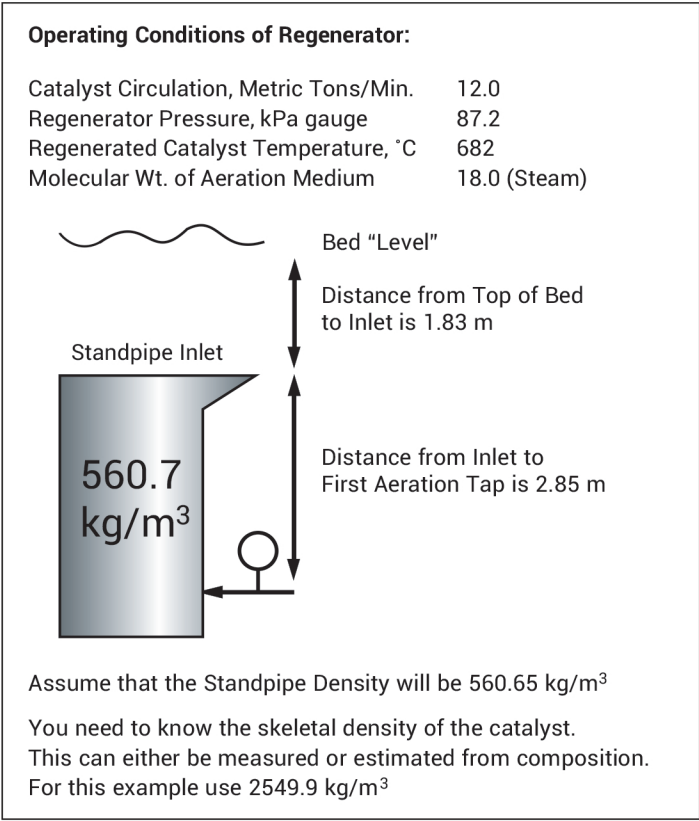


Figure 6. Calculation of Aeration Requirements

You will also need to know the skeletal density of the equilibrium (not fresh) FCC catalyst being used. This can either be measured using helium pycnometry, or the skeletal density can be approximated from the calculation below:

$$\rho_{\text{skeletal}} = \frac{1000}{\frac{\text{Al}_2\text{O}_3}{3.4} + \frac{\text{SiO}_2}{2.1}} \quad (3)$$

Where:

ρ_{skeletal} = Skeletal density of catalyst, kg/m³

Al₂O₃ = Weight fraction Alumina in catalyst

SiO₂ = Weight fraction silica in catalyst

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For this example, a skeletal density of 2549.9 kg/m³ was measured using the equilibrium catalyst.

1) Calculate the volume of the catalyst emulsion that is traveling down the standpipe per minute:

$$1000 \frac{Q_{\text{catalyst}}}{\rho_{\text{emulsion}}} = V_{\text{emulsion}} \quad (4)$$

Or

$$V_{\text{Emulsion}} = 1000 \frac{(12.0)}{560.65} = 21.40 \text{ m}^3/\text{min}$$

Where:

Q_{Catalyst} = Catalyst circulation, metric tons per minute.

V_{emulsion} = Volume of fluidized catalyst emulsion m³/min.

ρ_{emulsion} = The assumed stand pipe fluidized density of 560.65 kg/m³.

2) Calculate the total volume of interstitial and intraparticle gas that is circulated with the catalyst:

$$V_{\text{gas}} = V_{\text{emulsion}} \left(1 - \left(\frac{\rho_{\text{emulsion}}}{\rho_{\text{skeletal}}} \right) \right) \quad (5)$$

Or

$$V_{\text{gas}} = 21.40 \left(1 - \left(\frac{560.65}{2549.9} \right) \right)$$

Where:

V_{Gas} = Volume of gas circulated down the standpipe with the catalyst, m³/min.

3) Calculate the absolute pressure at the standpipe inlet, and the first aeration tap:

The pressure at the Inlet is:

$$P_{\text{Inlet}} = P_{\text{Dilute}} + \frac{(\rho_{\text{emulsion}})(g)(\Delta H_{(\text{Inlet} - \text{Surface})})}{1000} \quad (6)$$

Or

$$P_{\text{Inlet}} = (82.74 + 101.32) + \frac{(560.65)(9.81)(1.83)}{1000} = 194.12 \text{ kPa Absolute}$$

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³The circulation of the catalyst in the standpipe actually pumps the gas that occupies the spaces between (and inside) the particles down the standpipe with the catalyst.

The minimum fluidization velocity of FCC catalyst is on the order of 0.003m/second, while the velocity of the catalyst descending the standpipe is several orders of magnitude higher than this. So the gas that is in the continuous emulsion phase between and inside the catalyst particles is, in effect, dragged down the standpipe with the catalyst.

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The pressure at Tap 1 is:

$$P_{\text{Tap 1}} = P_{\text{Inlet}} + \frac{(\rho_{\text{emulsion}})(g)(\Delta H_{\text{(Tap-1 Inlet)}})}{1000}$$

Or

$$P_{\text{Tap 1}} = 194.12 + \frac{(560.65)(9.81)(2.85)}{1000}$$
$$= 209.80 \text{ kPa}$$

Where:

- P_{Inlet} = Pressure at the standpipe inlet, kPa absolute.
- $P_{\text{Tap 1}}$ = Pressure in the standpipe at the location of the first aeration tap down from the standpipe inlet, kPa absolute.
- P_{Dilute} = Pressure in the dilute phase of the vessel, above the catalyst bed, kPa absolute.
- $\Delta H_{\text{Inlet Surface}}$ = Height of the catalyst bed above the inlet to the standpipe, meters.
- $\Delta H_{\text{Tap 1-Inlet}}$ = Difference in depth between the location of the standpipe inlet and the first aeration tap, meters.
- ρ_{Emulsion} = Assumed density of the fluidized emulsion (560.65 kg/m³).
- g = Gravitational Constant, 9.81m/sec².

4) The change in gas volume due the pressure increase can then be calculated:

$$\Delta V_{\text{gas}} = V_{\text{gas}} - \frac{V_{\text{gas}} P_{\text{Inlet}}}{P_{\text{Tap 1}}}$$

Or

$$\Delta V_{\text{gas}} = 16.70 - \frac{(16.70)(194.12)}{209.80}$$
$$= 1.25 \text{ m}^3/\text{min}$$

Where:

ΔV_{Gas} = The change in gas volume at the temperature and pressure of the standpipe due to compression.

In order to counteract the compression effect and restore the needed volume to the catalyst emulsion, an incremental 1.25m³ of gas per minute (at 682.2°C., 209.80 kPa absolute) must be

injected into the standpipe at Tap 1. Using a molecular weight of 18.0 and PV=nRT this works out to 0.59 kg/min of steam at this tap location.

The theoretical aeration requirement serves as a useful bench mark to judge aeration rates when first examining the operation of the standpipe. However, few FCC units actually operate with exactly this quantity of aeration. In the real world, the actual aeration rate should initially be set to approximately 60-70% of this theoretical aeration requirement. Subsequent adjustment of the aeration rates from this initial point can then be used to seek out additional improvements. Some FCC units will end up operating somewhat above the theoretical aeration requirement, while others will operate below this theoretical aeration rate. In any case the best place to start is with an aeration rate that is 60-70% of theoretical.

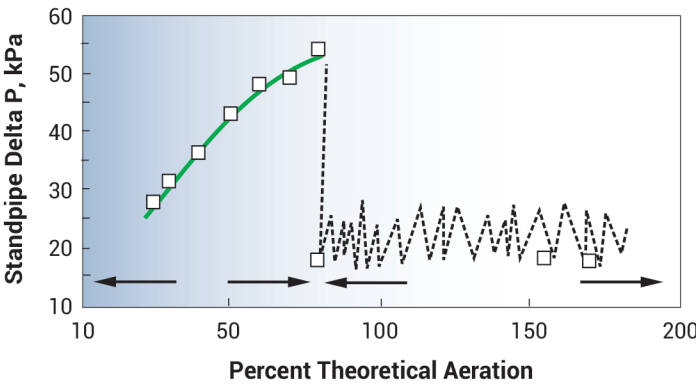


Figure 7. Standpipe Delta P

Figure 7 which is taken from a paper by R.E. Wrench, J.W. Wilson, and G. Guglietta³ shows how the pressure generated in a standpipe responds to variations in aeration rates. Note that over-aeration produces a dramatic loss of standpipe pressure. This behavior provides another good reason to use less than the full theoretical aeration rate when first setting up standpipe aeration.

It should be expected that as the physical properties of the equilibrium catalyst change, the shape of the aeration response curve shown in Figure 7 will also change. As the MSER of the equilibrium catalyst increases, the more tolerant it becomes to improper aeration.

Note that the aeration requirements of a standpipe is dependent on the catalyst circulation rate. So it is convenient to calculate the aeration requirement in terms of kg aeration per metric ton of catalyst circulated. In this example, the theoretical aeration at the first tap is 0.049 kg steam/metric ton of catalyst circulation.

Tap #	Tap Location, Meters Below Bed Surface	ΔH, Meters	Aeration Required, kg/min of Steam
Inlet	1.83	1.83	None
1	4.68	2.85	0.59
2	8.18	3.50	0.73
3	11.68	3.50	0.73
4	15.18	3.50	0.73
5	18.68	3.50	0.73
6	22.18	3.50	0.73
7	25.68	3.50	0.73
8	29.18	3.50	0.73
9	32.68	3.50	0.73
10	36.18	3.50	0.73

Table 1

The aeration calculation should be repeated incrementally from tap to tap down the length of the entire FCC standpipe. All of the actual aeration rates can then be compared to the theoretical bench marks provided by the calculation. Often this exercise will reveal that some portion of the standpipe is being improperly aerated.

When doing these aeration calculations along the length of the standpipe, it is handy to know that if the distances between the taps are equal, then the theoretical aeration required by the equally spaced taps will all be the same. Table 1 illustrates this for the regenerator used in the example above. Aeration taps 2 through 10 are all equally spaced at a distance of 3.5 meters from each other.

Standpipe Compression Requirements

Calculating the change in catalyst emulsion density that is taking place in the standpipe from tap to tap is also very revealing. As was mentioned earlier, there is only a very limited range of densities over which FCC catalyst will remain fluid. If the increase in pressure from tap to tap is too large, the catalyst

will be compressed past its point of incipient fluidization.

Using data from the previous example, the percent change in catalyst density required from tap to tap can be calculated from:

$$\Delta \rho_{\text{Emulsion}} \% = 100 \frac{\Delta V_{\text{Gas}}}{V_{\text{Emulsion}}}$$

Or using the numbers from Example 1:

$$\Delta \rho_{\text{Emulsion}} = 100 \frac{1.25}{21.40} = 5.84\%$$

Where:

$\Delta \rho_{\text{Emulsion}}$ = The percent change in emulsion density that is taking place from tap to tap.

What we are really doing here is calculating the amount of compression that the standpipe is requiring the catalyst to undergo. The greater the required percentage increase in density from tap to tap, the more prone the standpipe is to circulation difficulties. Calculating the percentage compression from tap to tap, often pinpoints where the FCC standpipe will be most likely to experience compression problems. FCC units that are suffering from catalyst over-compression, and

the subsequent loss of fluidization that it brings on, will often find that these problems are occurring in the upper half of the standpipe because this is where the greatest amount of compression per meter of descent takes place in the standpipe.

This standpipe compression requirement is a function of the FCC design pressure, and the spacing between the taps on the FCC standpipes. For example, it is commonly observed that lower pressure FCC units, where the regenerator may be designed to operate at 82 kPa gauge (12 psig), generally have much more difficulty circulating catalyst in standpipes than do higher pressure designs where the regenerator may be operating at 207 kPa gauge (30 psig). A quick calculation of standpipe compression requirements reveals that the low pressure designs inherently have much higher standpipe compression requirement, per meter of standpipe descent, than do the higher pressure designs.

Table 2 shows how the compression requirements for a standpipe change dramatically with respect to the dilute phase pressure of the vessel from which they are drawing catalyst.

The standpipe that is operating at the lower design pressure requires the catalyst to undergo significantly more compression between the aeration taps. In fact, at the top of the standpipe where the compression requirements are greatest, the low pressure design shown here requires 58% more catalyst compression per meter of standpipe descent.

One way to mitigate this compression requirement when the unit is designed for lower pressure, is to place the aeration taps closer together along the length of the standpipe.

As a rule, the aeration taps for low pressure standpipes should normally be spaced so that less than 4.5-5.0 percent compression is required between the taps.

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Tap #	Tap Location, Meters Below Bed Surface	ΔH , Meters	Percent Compression Required in Standpipe	
			Dilute Pressure 82.7 kPa Gauge	Dilute Pressure 206.0 kPa Gauge
Inlet	1.83	1.83		
1	4.68	2.85	5.84	3.67
2	8.18	3.50	6.56	4.26
3	11.68	3.50	6.05	4.04
4	15.18	3.50	5.61	3.84
5	18.68	3.50	5.24	3.66
6	22.18	3.50	4.91	3.50
7	25.68	3.50	4.62	3.35
8	29.18	3.50	4.36	3.21
9	32.68	3.50	4.13	3.08
10	36.18	3.50	3.92	2.97

Table 2

By keeping the compression requirement low, the standpipe circulation will be more tolerant of the changes in catalyst particle size distribution that accompany cyclone deterioration at the end of a run.

In terms of absolute numbers, 4.5 or 5.0 percent compression does not seem very high. However, if the unit is circulating a catalyst with a low stable expansion ratio (Low 0- 40 fines content and high ABD), then a 5.0 percent compression requirement in the standpipe can create catalyst circulation problems very quickly.

Choice of Aeration Media

Inspection of Equations 1 and 2 suggests that if the aeration media has a higher density and a higher viscosity, then the MSER for the system will be higher. Air is significantly higher than steam in both viscosity and density.

Thus, changing the aeration media from steam to air in regenerator standpipes that are suffering from compression problems has sometimes produced a dramatic improvement in catalyst circulation. If, due to poor

cyclone performance, the particle size distribution and density of the catalyst have moved into a region where the catalyst has trouble circulating in a standpipe with a 5.0 percent compression requirement, then changing the aeration media from steam to air can increase the compression tolerance (Effective MSER) to almost 1.08. This type of change in compression tolerance from 1.05 to 1.08 represents almost 60 percent improvement.

The possibility of condensate slugging into the standpipe is also greatly reduced by using air instead of steam.

The refiner should be aware that there are occasional gasoline gum or stability problems that can arise from the additional oxygen that is carried into the reactor by air in the regenerator standpipe. But these problems are relatively infrequent, and if they do occur, then the standpipe can be switched back to steam.

Note that this change in aeration medium is only appropriate in units that are operating with complete combustion in the regenerator.

Catalyst Design

In order to help mitigate a refiners' catalyst circulation problems, there are a number of things that the catalyst manufacturer can do to the catalyst.

First of all, if the FCC unit is limited in the amount of catalyst that it can circulate, then an increase in equilibrium catalyst activity should be considered. This will allow the refiner to achieve his best possible conversion with the limited catalyst circulation that is available. Increasing the activity of the equilibrium catalyst will also raise the regenerator temperature, which in turn will reduce the amount of catalyst that must be circulated at a given set of operating conditions. These two effects complement each other nicely.

Equations 1 and 2 along with Figure 5 clearly show that the Maximum Stable Expansion Ratio of the equilibrium FCC catalyst is a function of catalyst ABD and the 0-40 micron fines content of the inventory. Manufacturers of FCC catalyst have a great deal of flexibility in their manufacturing process which allows them to modify the ABD of the equilibrium catalyst without changing the chemical composition, or the catalytic selectivity patterns of the catalyst. Thus, a reduction of the equilibrium ABD can be designed into the fresh catalyst so that the MSER of the equilibrium catalyst can be enhanced.

In addition, the particle size distribution of the fresh catalyst can be modified in favor of a smaller average particle size with a higher 0-40 micron fines content which also tends to aid circulation.

Attrition resistance of the catalyst is another feature that can be modified so that the tendency to generate 0-40 micron fines can be enhanced. This is sometimes helpful when the cyclones have deteriorated and the ability of the FCC unit to hold the necessary 0-40 micron fines in its inventory is diminished.

By judicious application of these principles, the catalyst manufacturer can provide the refiner with a great deal of relief from standpipe circulation problems.

Pulling it All Together

From the foregoing discussion it should be clear that there are really four disciplines that need to be examined when trouble-shooting catalyst circulation problems in standpipes:

1. The Design of the FCC Unit Itself.
2. The FCC Unit Operations.
3. The Fluidization properties of the Equilibrium FCC Catalyst.
4. The Design of the Fresh Catalyst.

The FCC standpipe design needs to be looked at to confirm that its compression requirements are reasonable, to determine where the standpipe is making the most demands on the circulating catalyst, and to determine what the theoretical aeration bench marks are.

FCC operations need to be looked at to insure that the standpipe is being operated properly, and to insure that the rest of the FCC hardware is really doing what it is suppose to be doing. For example, a false level reading can trigger circulation difficulty by upsetting the bed levels which may uncover the cyclone diplegs, etc. One thing leads to another, and soon the fines have been lost from the inventory, and the standpipe circulation is in jeopardy.

Since the cyclone operation determines the particle size distribution of the equilibrium catalyst, an examination of cyclone performance should be considered an integral part of trouble-shooting standpipe circulation problems.

As shown above, the equilibrium catalyst properties provide much indirect information about how compression tolerant the catalyst will be in the standpipe. Thus, the equilibrium catalyst properties should be closely scrutinized for any subtle changes that may have triggered the standpipe upset.

Since a great deal of relief can often be obtained by modifying the fresh catalyst design, the catalyst manufacturer should be consulted to determine how much latitude is available for changing physical properties or activity. Modification of the fresh catalyst design to mitigate circulation difficulties is just another example of the benefits that accrue from close cooperation between the refiner and the FCC catalyst manufacturer.

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