
Fine Powder Design – Flow Rate Control

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Engineers must often control the mass flow rate from a handling system by using a volumetric feed device. This poses several problems. Accurate control requires three conditions: consistent bulk density, geometries that are not flow rate limited, and orifice sizes greater than cohesive hang-up conditions. Flow rate limitations are often severe and it is difficult to tell the difference between a slow flow rate limited condition and a cohesive hang-up.

Fine powders have two flow modes under gravity feed conditions. If there is enough gas entrained in the material, then the bulk solid becomes semi-fluidized and behaves as a liquid flowing from a container. In this case, the flow rate limitation is governed by acceleration of the semi-fluidized bulk material through the container. An active flow channel forms around an orifice with a conical shape or conforms to the shape of the container if the wall friction angle is small enough to induce mass flow. In either case, convergence of the flow channel controls acceleration or increase in velocity through the outlet. This limitation results in very fast flow rates through containers.

There is another reason for flow rate limitations in process equipment. Fine materials consolidate as they flow through a bin. If consolidation occurs slowly, then gas contained in interstitial pores of the bulk material leaves the bulk material through the top material surface. As this compressed and de-aerated material approaches the hopper outlet, it expands to flow from the outlet. This expansion results in a negative gas pressure formation near the hopper outlet (Figure 1). Gas attempts to rush in to equalize this negative gauge pressure. If the permeability is low, this process takes time. The negative gas pressure gradient then persists, resulting in partial support of material flowing from the outlet and creating a very slow flow rate through the hopper. Both the compressibility and permeability of the bulk material are required to compute the value of this rate limitation.

Permeability is the superficial velocity of gas or fluid passing through bulk material when the pressure drop across the bulk material equals the weight density of the bulk. It can be thought of as an incipient fluidization velocity, except it is measured as a function of the stress applied to the bulk material. However, the value of the permeability extrapolated to zero stress is identically equal to the incipient fluidization velocity. Permeability data is used to determine pressure drops in packed bed operation. It is also used to determine limiting flow rates where the resistance to gas flow is the key limiting factor to solids flow.

The other property used to compute this limiting flow rate is the bulk density. Bulk density may seem like an intrinsically simple property. It is the weight of the particles divided by the combined volume of the particles and the interstitial voids surrounding the particles. However, it

is a function of the stress level and strain history of the material. We measure it using uniaxial compression of a loosely packed bulk material.

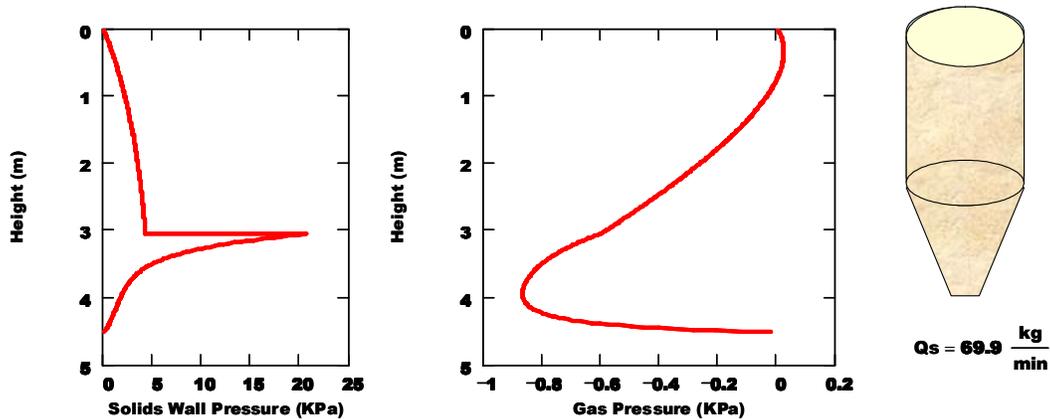
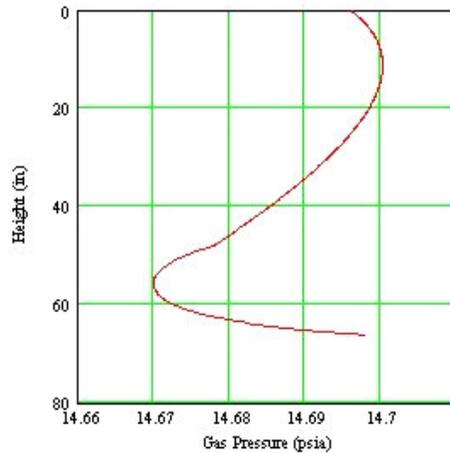


Figure 1. Gas pressure in process equipment resulting in flow limitations

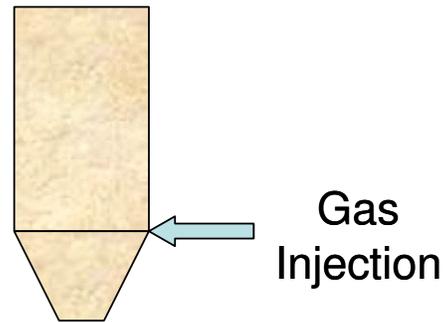
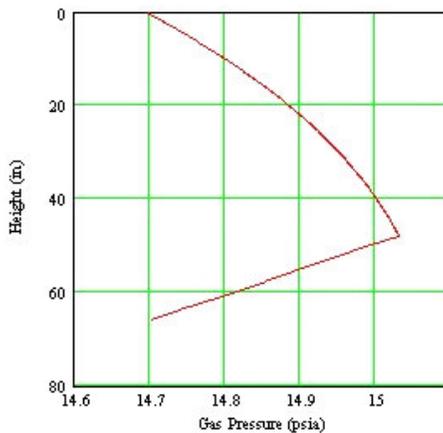
Compression of material during flow causes a change in the material porosity. This porosity change dictates the quantity of gas that must be injected into the bulk material to overcome negative gas pressure within the solids during flow. Permeability governs how fast this quantity of gas can pass through the bulk material. The combination of both these effects governs how fast a fully de-aerated material will flow from an outlet. Generally, this is at least an order of magnitude less than the acceleration limit. The solution to this problem is to inject gas at the right location and limit the right flow rate and pressure (Figure 2).

The amount of gas needed is only that required to match the gas squeezed out of the material during normal flow. The location and amount of gas injection are critical to proper operation. Too much gas aerates the material and results in uncontrolled flooding and flushing. Too little gas or gas injected in the wrong location will be insufficient to overcome flow rate limitations. Sometimes multiple injection locations must be used to achieve reliable flow. The degree of material cohesion and how close the material is to arching over outlets will also affect flow rates from the process vessel. In some instances, gas injection will change the mass flow and hang-up characteristics of the process vessel and this must be evaluated to assure gas injection will not cause other flow problems.

We use our proprietary computer program to compute limiting flow rates from bins, hoppers, blenders, feeders, and other process equipment. This program will examine your particular process vessel geometry and use measured flow properties to compute the expected flow rate limitations as well as the optimal gas injection placement and quantity to achieve reliable flow. It will determine if gas injection will initiate funnel flow or hang-up behavior and provides a means of solving your flow rate limitation problem.



Limiting flow rate of 25 lb/min



Gas injection increases solids flow rate to 280 lb/min

Figure 2. Example of how gas injection solves flow rate limitations

Sometimes the problem is too much gas entrained in the system. In this case, we can use our proprietary computer programs to compute the de-aeration time, maximum throughput or residence time required to de-aerate material during process operations. These calculations are based on measured flow properties and your particular geometry. Unit operations where de-aeration is important and can be evaluated are bins, hoppers, screws, roll presses, belt feeders, table feeders, tablet or package fill stations, tablet press operation, and die filling operations. Controlling the mass flow rate is often the critical step required to create robust process control. Let us help you optimize your process and bring it under control using scientifically proven principles of operation.