Knowing Your Material: Achieving Successful Process Design

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The Issue. Currently, many processes that handle bulk solids are not operating efficiently. Some are subject to occasional, or even frequent, hang-ups. Others experience erratic flow rate problems due to rathole collapse, aerated material, poor gas injection, or lack of mass flow. Still others are tasked with combining dissimilar products and maintaining this mixture in uniform condition during handling and packaging. Hang-ups, erratic flow rates, and segregation appear to be major causes of handling systems problems. At this time, we will only consider the case where hang-ups are present in the process. Let's identify some general guidelines to avoid these situations.

The Cause. Hang-ups are caused by the cohesive (or adhesive) nature of the bulk material. The material property responsible for this behavior is the unconfined yield strength of the bulk material. Strength is the major principle stress that is required to cause the bulk material to fail or shear after storage. Most engineers experience the effect of this property when material arches over the outlet of a process vessel. They may experience the influence of this property when attempting to empty a process vessel and notice stagnant regions where material is clinging to the walls. Bulk strength is some-times responsible for poor blending. The cohesive nature of the material will also control the weight variations in tablet dies and small packages. The solution to the arching problem is to make the outlet large enough to prevent the arch from forming. Obviously it is critical to measure the unconfined yield strength of the bulk material. However, the forces acting to break the arch depend on the bulk density. So, another critical material property to measure is the bulk density. The type of flow channel surrounding the outlet also has a significant impact on the material's propensity to arch. A flow channel which converges in all directions simultaneously has twice the propensity to arch as a flow channel that directs flow in one direction (plane flow). At first glance, solving the arching problem should be a straightforward task. One would simply measure the key flow properties (strength and density) and use these to compute the critical arching dimension and assure the process outlet is greater than this dimension. However, storage conditions and the amount of entrained air or local gas pressure gradients in the material play a significant role in inducing hang-ups due to external forces.

The Example. Consider erucamide pellets stored at elevated temperatures. Plastic creep occurs between these pellets, cementing particles together and resulting in a substantial gain in strength and arching propensity. In this case, the difference between the operation temperature and the glass transition temperature plays a major role in the strength of the bulk material. Quite often strength increases exponentially at temperatures above the glass transition, or softening, temperatures. Notice the increase in strength as a function of temperature (see Figure 1). A temperature of 36°C appears to be the critical temperature that initiates significant strength increase.

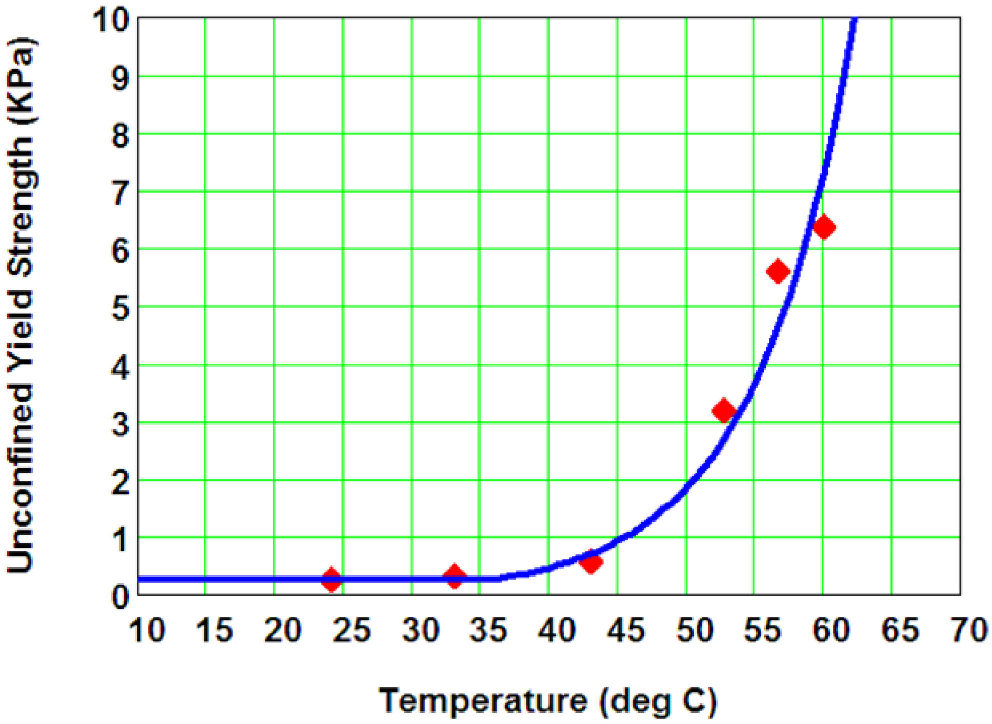

Figure 1. Strength of Erucamide as a function of temperature

Arching behavior is directly proportional to the bulk yield strength and, as a result, is a function of the process temperature, process temperature swings, storage time, environ-mental conditions (humid or not), aeration condition, and surface chemistry. A similar relationship can describe rathole behavior. Conversely, external forces or gas pressures applied to the material can change the forces acting to break the arch. Thus, gas pressure gradients can be instrumental in increasing or decreasing arching or rathole problems, depending on the direction they act. If the gas pressure gradient acts in a direction opposite to flow, then the gas pressure increases arching problems. If the gas pressure gradient acts in a direction compatible to flow, then the arch dimension decreases. Equation 1 summarizes this behavior.

$$AI = \frac{H_\theta \cdot fc}{\gamma \cdot g - \dfrac{dP}{dz}} \qquad (1)$$

Although it is more complex, the critical rathole dimension is also modified by local gas pressure gradients or other external forces. It is obvious from equation 1 that knowledge of the gas pressure gradient near the hopper outlet, or other places in the hopper, is critical to understanding arch formation in the process equipment. This is best seen in Figure 2. Bad placement of gas injection causes gas pressure gradients that result in arching within the upper hopper. A similar analysis could be done for rathole problems in aerated systems. These pressure profiles can be computed for any process equipment once the density, permeability, strength, and friction angles are known. This analysis allows optimal placement of air injection to prevent hang-up conditions. Likewise, changing gas pressure gradients will also change critical mass flow hopper angles. Thus, gas injection in the right location can help mass flow. Gas injection in the wrong location can hurt mass flow.

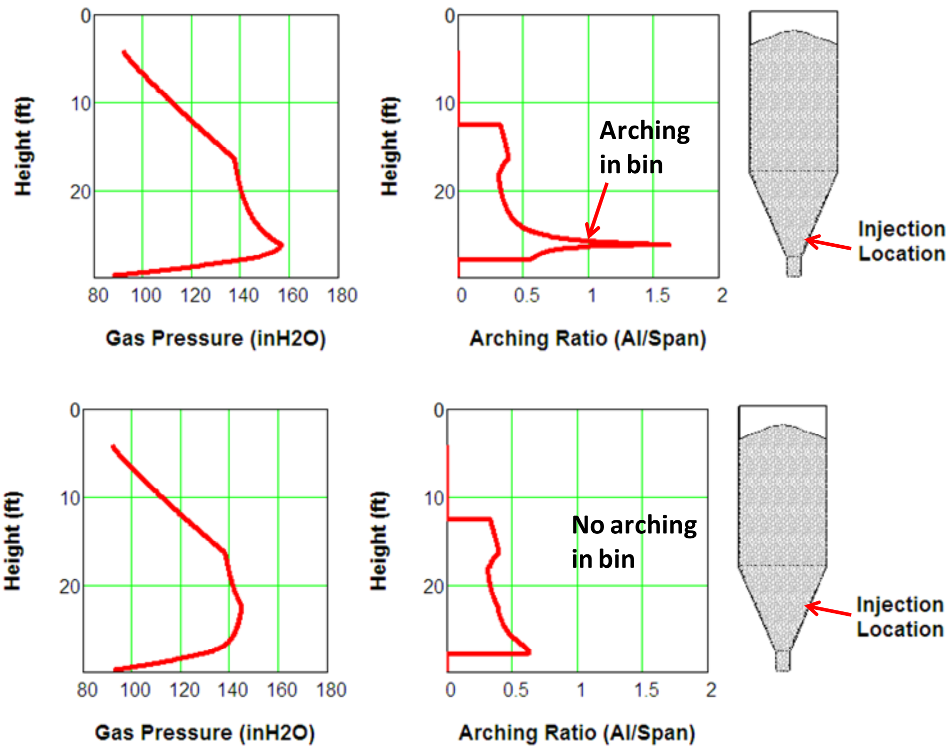

Figure 2. Arching in hopper due to bad placement of gas injection

The Guidelines. The solution of cohesive flow problems requires:

- Measure key flow properties at conditions similar to real process conditions. Knowledge of particle surface changes as a function of environment, system temperature, and surface chemistry will help identify the proper test conditions to measure these flow properties. We can aid you in selecting the right conditions for your process.
- Identify storage conditions, storage times, and any temperature swings that will aid in proper material flow property analysis. Your process will naturally be subject to typical day-night cycles or heating-cooling cycles. We can review your process and help you determine the magnitude of these changing process conditions. If the change is critical, we can also simulate these day-night temperature excursion using finite element software.

- Calculate the influence of external forces to determine if they will hurt or help cohesive hang-up conditions. This requires an analysis of your specific process and can be accomplished once key material flow properties are known.

It is clear that process hang-ups are a convoluted combination of process flow properties, environmental conditions, process geometry, and operation conditions. The solution for arching and/or rathole problems can often be found in controlling or changing one or more process variables. Our testing and modeling methods allow us to predict process behavior **in your process** so we can optimize process design based on key flow properties as well as typical thermodynamic properties of the bulk solid that are easily measured. Let us help you understand how to relate simple flow properties to critical process behavior.