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Conveying and feeding of calcium carbonate in plastics compounding

Calcium carbonate ($CaCO_3$) is one of the most popular mineral fillers used in the plastics industry. It is widely available around the world, easy to grind or reduce to a specific particle size, and compatible with a wide range of polymer resins. Plus it's economical.

As an additive in plastic compounds, $CaCO_3$ helps to decrease the surface energy and provide opacity and surface gloss, which improves the surface finish of the finished product. In addition, when the particle size is carefully controlled, $CaCO_3$ helps to increase both the impact strength and flexural modulus (stiffness) of the end product.

Calcium carbonate may be used with a myriad of thermoplastic resins. For example, polypropylene compounds are often filled with calcium carbonate to increase rigidity — an important requirement for operations at high temperatures. In polyvinyl chloride (PVC), calcium carbonate is used to produce compounds for flexible products, such as tubing, wire and cable insulation, latex gloves and trash bags. It is used in compounding rigid products such as extruded pipes, conduits and window profiles.

Conveying $CaCO_3$

The design of any feeding or pneumatic conveying system for bulk solids is heavily influenced by the bulk solid's particle shape, size (aspect ratio) and particle-size distribution, as well as the particle's roughness, hardness or abrasiveness, and density.

Material characteristics vary widely for calcium carbonate depending on its source and production process. The sieve analysis shown in the sidebar box (titled "Sieve Analysis") illustrates the difference in particle shape, particle size and particle-size distribution for two samples of calcium carbonate. The analysis shows the large number of particle interactions that make it impossible to establish a clear correlation between the filler's properties at the particle level and its flow behavior as a bulk solid.

When a material displays this sort of multiple personalities, pneumatic conveying systems cannot be purchased off-the-shelf; rather they must be engineered for each individual situation. Both systems engineering and equipment selection are affected by these differences, and laboratory tests are often necessary to determine a particular material's properties and behavior.

In general, a pneumatic conveying system consists of five basic components: the motive gas, conveying line, dispensing device, material-gas separator, and controls.

Dispensing devices

When selecting a dispensing device, care must be taken with some light and fluidizable grades of $CaCO_3$ that may flood the conveying lines. In such cases, a rotary valve, such as the one shown in Figure 1 should be considered to meter the material into the line. Rotary valves can be used for pickup in either pressure or vacuum pneumatic conveying systems. With adhesive grades of $CaCO_3$, the product will tend to build up and not release from the blades of a drop-through rotary valve. In this case, a blow-through style rotary valve is necessary. In this design, air is blown through each pocket as the valve turns, dislodging material from the blades. The installation of a fluidizing cone in the feed bin is also helpful in controlling the flow of the material.

Conveying lines

Calcium carbonate powders can cause many problems in conveying systems, as they often stick to the inside surfaces of hoppers, flood while being fed into convey lines, build up inside convey lines, and blind over filter bags and cartridges in receivers.

Rigid pipes may be used as the conveying line for $CaCoO_3$ that ranges from highly fluidizable to slightly adhesive. However, if the $CaCO_3$ tends to coat the interior of the convey line, a flexible hose should be considered because the flexing of the line can help to prevent buildup on the walls of the hose.

In vacuum-sequencing systems, it is a good practice to use a purge valve to allow the line to clear between conveying sequences. First, a shut-off valve at the pickup of a vacuum system is closed to allow vacuum to build in the line. Then the valve is opened, creating a pressure wave that helps to clean off any coating of material adhering to interior surfaces of the convey line.

Material-gas separator

Often $CaCO_3$ will adhere to the filter, causing it to blind over and reduce filter efficiency. For sticky grades of $CaCO_3$ using filter bags instead of pleated filter cartridges may help reduce the tendency of the $CaCO_3$ to stick to the filters. In extreme cases, the use of polytetrafluoroethylene (PTFE) filter media is recommended.

Some calcium carbonate grades may require a steeper discharge cone in order to allow for complete emptying of the hopper. Flow aids such as vibrators or fluidizing pads inside the receiver hopper will usually help ensure quicker and more complete discharge of the receiver.

Application example

The sieve analysis shown in the sidebar box (titled "Particle Interactions") illustrates the difference in particle shape, particle size and particle-size distribution for two samples of calcium carbonate. Sample A is a precipitated calcium carbonate (PCC) with a relatively low bulk density. Sample B is a granular calcium carbonate with a much higher bulk density.

Figure 2 shows a schematic representation of the pneumatic conveying system required to transfer the calcium carbonate from a storage bin into a feeding system in a compounding operation. In this example, a processor needs to transfer 4.5 tons/h (10,000 lb/h) of calcium carbonate from a storage bin (1), to a filter receiver (2), located on top of a rotary valve (3), for the extrusion of polypropylene (PP) and $CaCO_3$ at a plastics-compounding facility. The facility is located at 305 m (1,000 ft) elevation with an average daily temperature of 29.5°C (85°F) during the entire year.

The selected calcium carbonate sample would need to be pneumatically conveyed over 30 meters (100 ft) horizontal distance, and 15 meters (50 ft) vertical distance with four 90-degree angle elbows (4) present in the system. The blower (5) would be located in such a way that the air line would be 15 meters (50 ft) long (when combining horizontal and vertical distances) with no more than 2 elbows.

Material testing showed significant particle characteristic differences between the two $CaCO_3$ samples, which resulted in the selection of different equipment components, and different sizing considerations for the entire system. For instance, a higher blower horsepower (5) is required for calcium carbonate B to provide the increased system airflow and vacuum necessary to maintain dilute-phase conveying at the required rate.

Similarly, differences in the bulk density and particle characteristics determine the adjusted rotary valve (3) throughput to maintain the desired rate. To this end, for the much denser material B, the volumetric throughput is significantly lower than calcium carbonate sample A.

The diameter of the filter housing is determined by the *can velocity* (sometimes written as CAN velocity). The upward velocity or can velocity is a function of the container's cross-section (the smaller the container diameter the higher the can velocity), but it varies depending on the characteristics of the material being conveyed.

Maximum can velocity is defined as the largest vertical velocity through the filter housing that will allow the majority of material to fall out of the airstream. The filter cloth area for each material is based upon the filtering characteristics of each sample.

Particle size plays a large role in determining the necessary filter cloth area required to accommodate the the material. The larger the particle size, the easier it will be to separate from the airstream; therefore less filter cloth is required. Table 1 summarizes some of the different equipment requireents for the two samples of $CaCO_3$ described here.

Feeding $CaCO_3$

The selection of the appropriate feeding system for each of the illustrated calcium carbonate samples is determined by two main variables: the characteristics of the mineral filler (for instance, the particle size and shape, gas permeability, bulk density and angle of repose) and the required feedrate.

Loss-in-weight (LIW) feeders, such as the one shown in Figure 3, provide total containment of the raw material and dust and optimal feedrate performance to assure overall end product quality. LIW feeders are available in a variety of configurations, so that the hopper size, feeding device and weighbridge can be tailored to the specific material characteristics, flow properties and flowrates for the material to be fed.

Volumetric vs. gravimetric feeding

Most feeders may be categorized as volumetric or gravimetric. Volumetric feeders operate by delivering a certain volume of material per unit time and are typically the feeding solution with the lowest capital cost. However, volumetric screw feeders cannot detect or adjust to variations in a material's bulk density during operation. As a result, these feeders are typically most effective with relatively free-flowing materials that have consistent bulk density, such as pellets, and in applications where a guaranteed feeding accuracy is not crucial to the operation.

During gravimetric feeding, dry bulk material is fed into a process at a constant weight per unit of time. Gravimetric feeding provides better monitoring of the feeding process by providing a feedback loop that measures weight and speed. This helps to determine the actual weight of material being fed on a second-to-second basis.

Hopper selection

Once the size and type of feeder is established, a hopper of the appropriate shape and size must be selected to contain the right amount of filler required for the continuous plastics-compounding operation. Hoppers are available in cylindrical, asymmetrical and symmetrical shapes,and in sizes ranging from one liter to several hundred liters.

A feeder hopper is sized based upon the refill requirements of the feeder and the physical space available at the site. A general rule-of-thumb for calculating the appropriate size is 12 hopper refills per hour ,with the maximum fill level in the hopper at 80% of the hopper volume. A large hopper may not be desired because of incremental cost, space requirements, and the possibility of material compaction due to particle interactions.

Thus, hopper size selection is initially guided using the following theoretical calculation:

$$\textit{Hopper capacity} = \textit{Flowrate} / (\textit{Bulk density} \times 0.8 \times 12)$$

Precipitated calcium carbonate tends to compact in hoppers and may cause the formation of flow-stopping ratholes and bridges. Flow-aid devices that work by inducing particle-particle vibrations should be considered to ensure predictable flow by preventing the formation of highly dense material zones inside the hopper. In addition, This approach can help to reduce headroom requirements and eliminate cleaning concerns because there is no need to use mechanical agitators inside the hopper. For extremely cohesive materials alternative mechanical agitators are available.

Feeding devices

Feeding devices vary depending on the bulk material to be fed: single screw or Bulk Solids Pump™ (a patented product by K-Tron) for free-flowing powders and granulates, twin-screw feeders for difficult powders (Figure 4), vibratory trays for fibers and friable materials.

While a single-screw feeder may work with free-flowing grades of $CaCO_3$, a twin-screw feeder is generally recommended to achieve a reliable result. A variety of screw designs are available according to the flowrate and characteristics of the mineral filler (Figure 5). The most common screw profiles are concave, auger, spiral and double spiral. The objective of the screws is to discharge the bulk solids uniformly into the plastics compounding process. Screws also serve to stop the material flow when the screw feeder is stopped, and to prevent flooding effects with fluidizing bulk solids.

Calcium carbonate’s tendency to compact also occurs on metal surfaces like the feeder’s screws. For this reason, two intermeshing, co-rotating self-wiping screws are needed to keep the screw surfaces clean and free of material buildup.

Weighbridge

The weighing system used for the loss-in-weight feeding system can range from small-capacity platform scales to larger, three-point suspension scale systems. Today’s patented, digital weighing technology (K-Tron) provides weighing resolution of 1:4,000,000 in 80 ms resolution, and is designed to reduce vibration and temperature drift during operation.

Sample feeding system

Table 2 shows an example of ideal feeding systems for the two calcium carbonate samples described here.

Conclusion

Because calcium carbonate is so widely used in plastics-compounding operations, it is important to appreciate how much the success of the overall operation depends on its bulk material handling systems. The correct design of pneumatic conveying and feeding systems for calcium carbonate is not a trivial proposition., There are a number of variables that affect the flow of this often difficult powder, and the return on investment (ROI) of a plastics-compounding plant is directly impacted by the proper selection of the most cost-effective pneumatic conveying and feeding system. Particle characteristics, as well as material flow behavior (governed by, among other things, particle interactions with other particles, and particle interactions with the equipment and the environment) will influence the selection of equipment and system design.

Figures

Figure 1. When selecting a dispensing device, the characteristics of the bulk solid may dictate the use of a rotary valve, such as the one shown here. Rotary valves are particularly useful for light, fluidizable solids that may flood the conveying lines. They can be used for product pickup in either pressure or vacuum pneumatic conveying systems

Figure 2. In this typical vacuum conveying system, calcium carbonate is conveyed from a storage bin into a feeding system in a compounding operation. 1=storage bin; 2=filter receiver; 3=rotary valve; 4=convey line (orange) and air only line (blue); 5=blower; an inline filter is pictured between the filter receiver (2) and blower (5) to protect the blower from stray particles in the clean air line

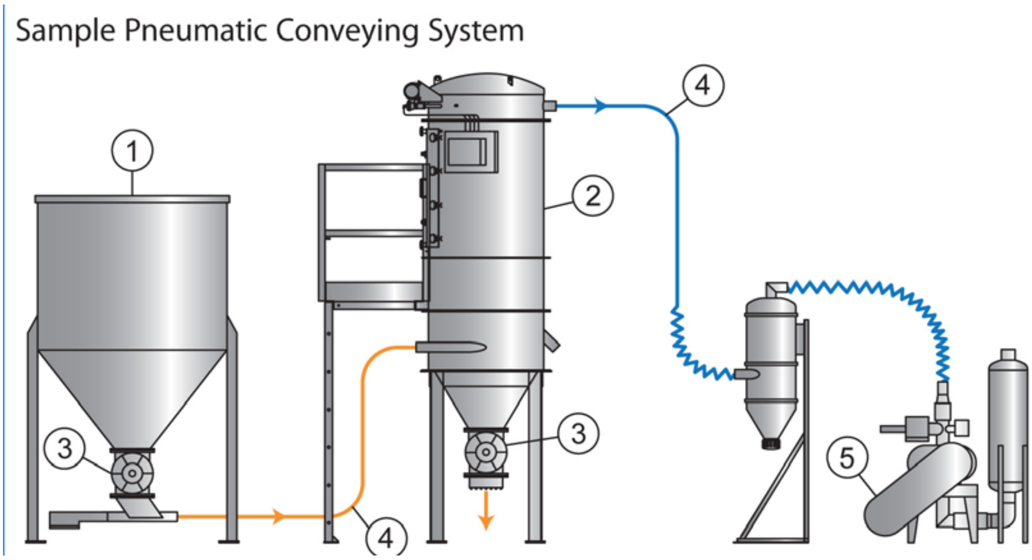


Figure 3. Loss-in-weight feeders dispense dry bulk materials into the process at a constant weight per unit of time. They provide a feedback loop that measures weight and adjusts motor speed to ensure that the actual weight of material being fed on a second-to-second basis is exactly what the recipe calls for

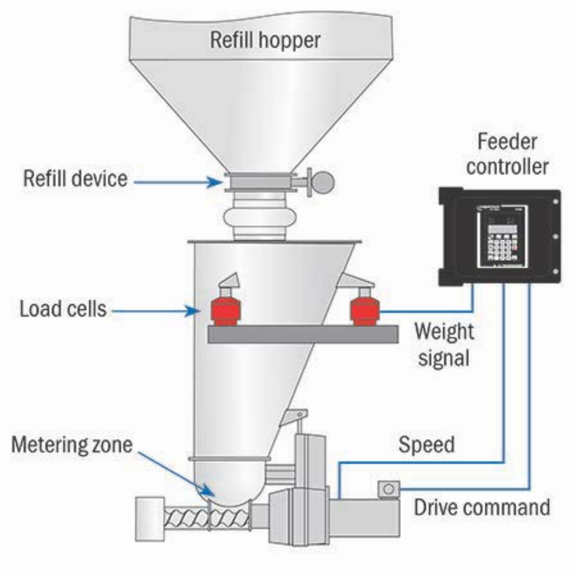


Figure 4. To prevent flooding with free-flowing grades of $CaCO_3$, twin-screw feeders are recommended.

Figure 5. These intermeshing twin screws can prevent flooding of fluidized material. A variety of feeder screw designs are available, depending on the flowrate and characteristics of the mineral filler

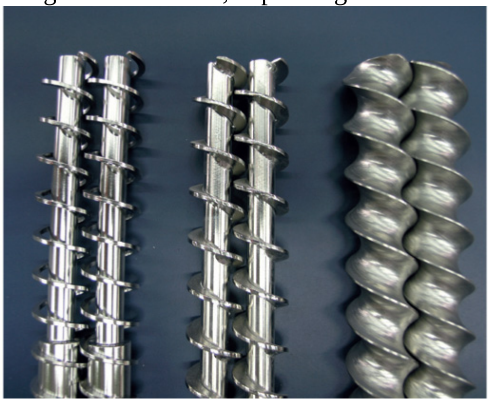


Table 1. Needs no caption

Table 1: Differences in Conveying Equipment Selection

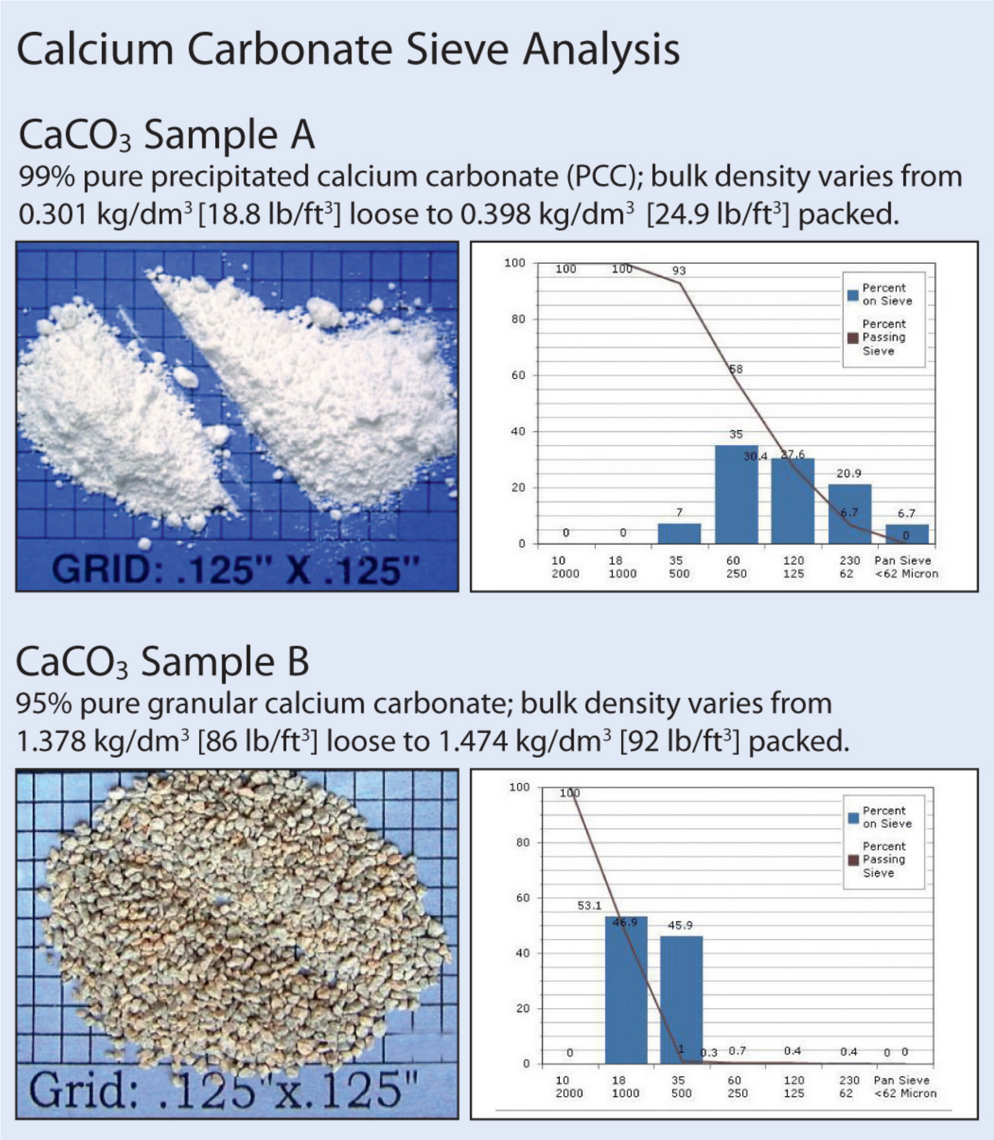
Equipment	*Sample A*	*Sample B*
Blower size	*16 kW [20 HP]*	*20 kW [25 HP]*
Rotary Valve Throughput	*15 m^3/hr [531 ft^3/hr]*	*3.6 m^3/hr [128 ft^3/hr]*
Rotary Valve Efficiency	*84%*	*92%*
Adjusted RV Throughput	*17.9 m^3/hr [632 ft^3/hr]*	*3.9 m^3/hr [139 ft^3/hr]*
Filter Housing Diameter	*1.4 m [54 in]*	*0.9 m [36 inches]*
Filter Cloth Area Required	*17.7 m^2 [191 ft^2]*	*7.5 m^2 [81 ft^2]*
Maximum Can Velocity	*21.3 m/min [70 ft/min]*	*No restriction*

Table 2. Needs no caption…

Table 2: Differences in Feeding Equipment Selection

Equipment	Sample A	Sample B
Feeder model	K2-ML-T60	K2-ML-D5-T35or-S60
Hopper size	180 dm^3	50 dm^3
Agitation	ActiFlow or Arch-breaker	none
Feeding Device	twin concave screws	single auger screw / twin auger or spiral screws
Weighbridge	3 load cells	D5 platform scale

SIDEBAR BOX 1



Sidebar 1 text:

Calcium Carbonate Sieve Analysis

CaCO3 Sample A
99% pure precipitated calcium carbonate (PCC); bulk density varies from 0.301 kg/dm3 [18.8 lb/ft3] loose to 0.398 kg/dm3 [24.9 lb/ft3] packed.

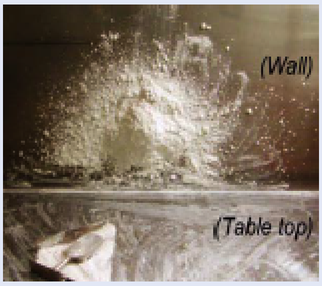
CaCO3 Sample B
95% pure granular calcium carbonate; bulk density varies from 1.378 kg/dm3 [86 lb/ft3] loose to 1.474 kg/dm3 [92 lb/ft3] packed.

SIDEBAR BOX 2 (text follows on next page)

Particle Interactions

Three distinctive relationships affect the flow behavior of mineral fillers in pneumatic conveying and feeding systems: Particle-particle, particle-equipment and particle-environment interactions.

Particle-Particle

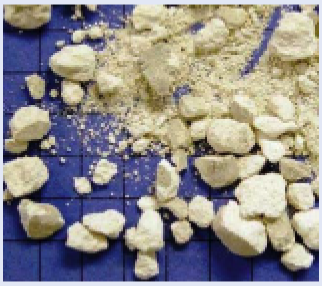


Particle-particle interactions are directly related to the filler's chemical composition and physical characteristics rather than bulk properties. The most important particle-particle forces are the electrostatic or van der Waals forces of attraction between molecules. As the separation between particles increases, the van der Waals forces decrease, explaining why the addition of small particles to cohesive powders improves their flowability. Other particle-particle forces include capillary forces, responsible for liquid bridge formation, and sintering forces, responsible for solid bridge formation. Capillary forces develop in the presence of water vapor in the gas phase whereas sintering forces develop when material migrates due to diffusion or viscous flow. Interparticle forces contribute to the cohesive characteristics of fine powders and their tendency to form aggregates or agglomerates.

Particle-Equipment

The flow of solid particles inside a vessel or a pipe is a function of two important characteristics, wall friction and shear strength. Wall friction relates to how particles slip on a contact surface while shear strength is the resistance that the powder bulk offers to deformation, or how particles slip relative to each other.

Particle-Environment



Particle-environment interactions deal with external forces (e.g., temperature, relative humidity, vibration, gravity, aeration, etc.) exerted over the aggregate of particles. The air Relative Humidity (RH) and the filler's hygroscopic nature are often coupled with increase cohesiveness because of inter-particle liquid bridges; temperature affects the particle's crystallinity behavior, promoting "caking", while pressure increases the contact points between particles, causing "compaction" or more inter-particle adhesion.

Sidebar 2 text:

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Particle-equipment interactions

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Particle-environment interactions

Particle-environment interactions deal with external forces (such as temperature, relative humidity, vibration, gravity, aeration and so on) that are exerted over the aggregate of particles. The air relative humidity (RH) and the filler's hygroscopic nature are often coupled with increased cohesiveness because of inter-particle liquid bridges. Temperature affects the particle's crystallinity behavior, thereby promoting "caking," while pressure increases the contact points between particles, thereby causing "compaction" or an increase in inter-particle adhesion.