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Technical Paper

Issues in Microfeeding

Spurred by pharmaceutical industry demand for continuous ultra-low-rate powder feeders where accuracy is measured in milligrams, today's microfeeding technology offers improved efficiency and automation

As anyone who works with bulk solid materials knows, accurately and reliably controlling the flow rate of material at normal process rates can be challenging. Add to the challenge the need to control the flow of some minor ingredients in the process in micro-regions as low as 20g/hr. Further compound the challenge by requiring a level of precision that permits only a scant few percent sample-to-sample variation. This is the challenge of microfeeding.

The development of microfeeding technology emerged primarily as a result of the recent decade's shift toward Process Automation Technology (PAT) as sanctioned by the FDA. This initiative has hastened application of continuous processing techniques in the pharmaceutical industry. Moving to a continuous process necessitates the elimination of manual feeding of minor ingredients and creates a real need for microfeeding technology.

The successful development of microfeeding technology represents a much-needed response to the pharmaceutical industry's requirement, and also offers processors in other industries a previously unavailable capability. A microfeeder can be applied in a variety of processes and industries: the micro-introduction of a powdered concentrate in plastics compounding, a trace component in energetics production, an option in low rate feeding of smaller sized micronizers, or as a continuous, on-line alternative to the traditional batch pre-mix approach for minor ingredients and additives.

Adopting a Microfeeding Mindset

Before addressing the design challenges of microfeeding it is important to first shift focus from the familiar notions of typical process feeding to the micro-realm of ultra-low-rate feeding.

STEP 1: Microfeeding's Guiding Principle

Unlike continuous, higher rate feeding, microfeeding tests the limits of measurement and control, and requires scrupulous attention be paid to every aspect of design and execution. As will be seen throughout this discussion, a single reality governs the challenge of continuous microfeeding: In microfeeding, everything matters.

STEP 2: Defining Terms

For the purposes discussed here microfeeding can be defined as controlling the flow of a powdered or other small-particle-size material at a range of feed rates from 2000 g/hr down to 20 g/ hr or lower. At 20g/hr, this translates to 0.33g/min or just 5.5mg/sec. Expressing this limit in terms of a second-to-second flow rate is intended to highlight the need to first consider the question of performance timescale, the time over which the allowable variability of flow rate is to be specified.

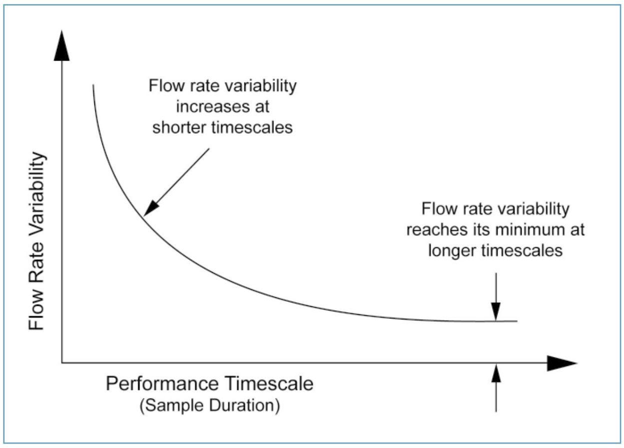

Figure 1 - Flow Rate Variability vs Feeder Performance Timescale

Coperion K-Tron's Model MT12 Twin Screw Loss-in-Weight Microfeeder

Figure 1 illustrates the typical relationship between flow rate variability and performance timescale. Both these parameters are dictated by process and product quality requirements: flow rate variability is commonly reflected in the familiar feeder accuracy repeatability statistic (e.g., +1.0% of sample average @ 2 Sigma). Performance timescale is the time basis for its sample-based measurement (i.e., sample duration). Here it is seen that flow rate variability achieves its minimum value -- a value that characterizes the feeder's ongoing performance level -- at longer performance timescales (sample durations). However, at shorter and shorter performance timescales, measured sample-to-sample variability grows. (The fact that no numbers are attached to Figure 1 is intentional; specifics depend totally on the mechanical performance of the feeder, the loss-in-weight control and the material.)

This relationship is universal in feeding and is also expected for several reasons. First, at a given feed rate, as sample duration decreases, sample weight decreases in proportion. Even if it were possible or practical to obtain physical second-to-second samples of a discharge stream, at some point, as sample duration and weight diminish, the ability to confidently resolve these sample weights becomes compromised, and deprives the feeder control system of the weight measurement integrity it needs to make useful control corrections. Measurement error actually affects both the feeder's ability to control and the sampling system's ability to provide a reliable measurement of accuracy. Also, as sample times get shorter the inherent timing errors of the sampling system and the control system have a larger impact.

Second, even if a near-instantaneous sample could be taken and its weight measured with sufficient precision, the control scheme of any gravimetric feeder could not, and should not, act on such a minimal and transient basis, lest it respond too slowly or, worse, act on false ambient effects or other sources of measurement error. By design, gravimetric feeder weighing and control systems that are suitable for application in microfeeding must be able to effectively identify and extract legitimate dynamic weight data in a process environment where the signal-to-noise ratio climbs ever steeper as the measurement timescale is reduced.

Third, apart from the more theoretical reasons covered above, a real-world assortment of physical and mechanical factors affect flow rate variability at short timescales but tend to average out in longer samples. Material properties such as particle size, cohesiveness, and through-the-feeder handling characteristics like screw fill uniformity and behavior at discharge have an especially strong impact on feed rate variability over short timescales. Factors common in the processing environment such as vibration, air currents, or other disturbances also act to reduce achievable feeding accuracies in short timescale applications (and especially in microfeeding where rates are so low). Finally, aspects relating to the feeder itself, such as screw pulsing, achievable weighing resolution, the type and quality of its signal processing, and the frequency of control updates among other factors all combine to contribute to the overall variability-vs.-timescale picture.

In contrast to most higher rate applications where the primary focus of concern is on the feeder's ongoing level of performance (reflected by typical catch sample durations of about 60 seconds), many microfeeding applications require that feeder performance be gauged based on performance timescales somewhat shorter than a minute. Thus, the factors presented above have special relevance to microfeeding applications where both sample size and duration are miniscule.

At a feed rate of 20g/hr, the three piles of material represent an hour's throughput (20g), a minute's discharge (0.33g) and second's dosing (0.005g). The dime shows physical scale.

STEP 3: Continuous Microfeeding as an Alternative to Batch Premixing

The development of microfeeding technology extends the range of achievable and reliable feed rate control of many powdered or similar materials to below 0.1 lb/hr. This capability complements existing low-rate feeding technologies to comprise an alternative to the traditional batch premix approach in proportioning minors, additives and other low-proportion components.

Batch premixing is well established as a means of preparing low-proportion ingredients in many applications. Lacking any practical alternative, processors have had to accept its innate costs, material handling complications and inefficiencies. Among these shortcomings is the prevalent reliance on expensive and potentially error-prone manual preparation along with possible safety, handling and containment/contamination issues. Also, when separately prepared for subsequent feeding into a continuous process, a batched premix or masterbatch, even when thoroughly mixed initially, runs the risk of becoming re-segregated in the intervening operations of handling, transport, and delivery to the premix feeder.

By combining the use of microfeeding technology with traditional low-rate-feeders, a continuous alternative to batch-based premixing emerges. The primary advantage of increased automation is the minimization of many of the safety and handling concerns of premixing along with the prospect of significantly reducing ongoing operating costs. Additionally, on-line continuous introduction of low-proportion components avoids segregation concerns altogether and in some applications presents unique opportunities to further minimize the proportion of critical, high-cost ingredients. And finally, unlike the premix approach where batched components must be introduced into the process at a single specific point, the continuous option provides the added flexibility to introduce low-proportion ingredients individually, wherever in the process that makes sense.

Closeup of MT12 Microfeeder with discharge tube removed.

STEP 4: Setting Performance Expectations

What constitutes acceptable performance in microfeeding applications? Considering the few manufacturers who even offer such a capability and the range of potential microfeeding applications industrywide, it is not appropriate to state specific values for feeder repeatability nor is it appropriate to state a specific measurement timescale.

In fact, as a starting point these values are dictated not by the capabilities of any available microfeeding equipment, but by the desired quality, properties and attributes of the end product being produced, as reflected by its composition and the degree of permissible ingredient variation. Only then, and by working backwards from these product/quality based standards, can feeder performance requirements be reasonably specified.

Given the long history of batch premixing in which highly precise static weighments of even the lowest-proportion components are the norm, it is understandable that such attainable precision can become regarded as an essential product/quality requirement rather than simply a benefit of the premix approach. Confusing the crucial difference between required and attainable proportioning precision of minors and additives can cause processors to overlook continuous formulation as an alternative, and miss its advantages of automation and improved process efficiency.

Of special relevance to continuous formulation involving low-proportion ingredients is the notion referred to here as the 'recipe effect.' This effect relates to the different bases upon which the processor typically specifies permissible ingredient variation and the feeder manufacturer expresses feeder performance. Rightly focused on the totality of the formulation, the processor typically expresses the allowable variation of each ingredient in percent of total recipe, whereas feeder manufacturers necessarily evaluate and express their feed-rate-variability (repeatability) performance on the basis of percent of feeder rate.

For example, a processor may permit a minor ingredient to vary between 2.95 and 3.05% in the total recipe, representing an allowable variation of only + 0.05% of total recipe. But when re-expressed from the perspective of the ingredient feeder, that same variation translates to an allowable feed rate variability of + 1.67% of feeder set rate (i.e., = + 0.05/3.00). Thus, if the feeder limits ingredient variability to + 1.67% of set rate, it is sufficiently accurate to satisfy the stringent recipe-based requirement. While variabilities less than this value certainly act to further improve formulation consistency, the processor's specification of a recipe's ingredient proportion tolerances directly defines the upper boundary of acceptable feeder performance.

By translating even rigorously demanding standards of recipe-based ingredient variability into their corresponding ingredient-based requirements, continuous low-rate and microfeeding techniques can be considered as a viable candidate for these proportioning applications. (Note that the relevance of the recipe effect extends to all product components, whether present in low or high proportion. Since its influence varies inversely with proportion, the recipe effect's beneficial influence on feeding accuracy requirements remains strongest for minor, low-rate components -- precisely those ingredients presenting the greatest feeding challenge.)

In critical stand-alone, single ingredient microfeeding applications such as supplying material to a particle-sizing jet mill or micronizer, the best achievable feeder performance is sought. In these and similar applications, the uniformity of feeder discharge strongly influences the effectiveness of the intended operation. Here, by offering process-level performance at very low rates, microfeeding technology directly contributes to the achievement of improved processing efficiency.

Lastly, regarding the specification of feeder performance timescale requirements (sampling duration), a careful assessment of the process and the specific operations performed after feeding or proportioning should provide a reasonable basis upon which to specify the sampling timescale. For example, if separately mixed after formulation, an appropriate sampling duration for the measurement of feeder accuracy would be on the order of the time spent in active mixing. Or, if proportioning to an extruder, a sample duration approximating extruder residence time would be reasonable. In applications where nearby downstream operations do not provide a clear guide to an appropriate performance timescale, a value must be determined through other acceptable, process-based means. However, as should be clear from Step 2 above, imposing an arbitrary, unnecessarily brief sampling duration -- especially where low-rate microfeeding is concerned -- succeeds only in corrupting the relevance of feeder performance measurement.

Types of Microfeeders

Understandably, a material's physical and handling characteristics strongly affect the consistency at which it can be fed, or whether it can even be fed at all at these very low rates. Particle size, cohesiveness and other properties combine to determine a specific material's potential for successful microfeeding. Thus, the first step in considering microfeeding is to evaluate the material itself. This should involve close consultation with the feeder manufacturer and will often require laboratory testing.

The vast majority of low rate and microfeeding applications employ the loss-in-weight principle of operation in which the feeding unit, supply hopper and material are isolated and continually weighed. Discharge rate is then controlled to achieve the desired loss in system weight per unit time. The types of metering device capable of feeding at very low rates include the screw, cone, vibratory tray and disc varieties. Each is summarized below and illustrated in Figure 2 (next page).

Screw Type – When applied at very low rates this form of metering device typically employs twin screws, located at the bottom of the feeder's supply bin to capture and transport the material to discharge. The uniformity with which the material fills the screws' advancing cavities influences the achievable degree of feed rate control. Advantages of this approach include comparatively good linearity, a partial positive-displacement action provided by the screws' advancing cavities, generally good self-cleaning characteristics, and anti-flooding design. Disadvantages include maximum particle size limitations and the possibility of discharge pulsing at low screw speeds.

Cone Type – This approach involves a hollow cone, positioned horizontally and partially filled with material. As the cone is slowly rotated the material adopts its natural angle of repose within the cone and cascades from its smaller open end to discharge. Cone feeding is primarily used for free-flowing pelletized or granular materials displaying consistent cascading behavior. It is generally not used with powdered materials.

Vibratory Tray Type – A familiar strategy, vibration is an effective means of control at low rates. Like the cone feeder, the vibratory approach is used mainly on free-flowing pelletized or granular materials. Some vibratory feeders exhibit non-linearity and stability concerns, limiting use to constant-rate or low turndown applications. With advanced loss-in-weight controls, a vibratory feeder can be made linear and offer consistency over time and a high turndown. At very low rates, however, a vibratory feeder is only good for coarse granular materials. Most powders are too sticky and most pellets require a higher minimum energy to move them than the desired rate will allow.

Disc Type – Mainly appropriate for powders and other small-particle-sized materials, disc feeding involves a round plate with a circumferential channel or groove cut near its edge or small discrete pockets. The grooved disc is positioned off center at the bottom of the feeder's bin so that the grooved region emerges from beneath the bin during a portion of its rotation. In the bin, material fills the channel and is sheared as the rotating groove emerges from the bin. Once outside, a diverter extracts the material and moves it off the disc's edge to discharge. While rotation speed can be closely controlled and metering groove geometry engineered to the application, concerns relating to the uniformity of channel fill and the consistency of the subsequent shearing action prior to material diversion require special attention when feeding powders that are cohesive, tend to clump, or otherwise hesitate occupying a small void.

Anatomy of a Microfeeder

Detailing the design considerations for microfeeding is best approached by addressing its three main elements: weighing, control and metering systems.

Weighing System - Achieving precise feed rate control begins with accurate weight measurement. In very low rate loss-in-weight feeding where total feeder system weight declines at a low rate and the measurement environment is frequently far from ideal, the challenge is to obtain legitimate, useable weight measurements in the shortest possible time.

To accomplish this demanding task, the first and most basic requirement is for reliably high weighing resolution. High resolution is needed to precisely discern the small differences in system weight that characterize low rate feeding and to permit more frequent corrective adjustments to metering rate, enhancing moment-to-moment feeder performance.

Over recent decades, developments and refinements in digital process weighing

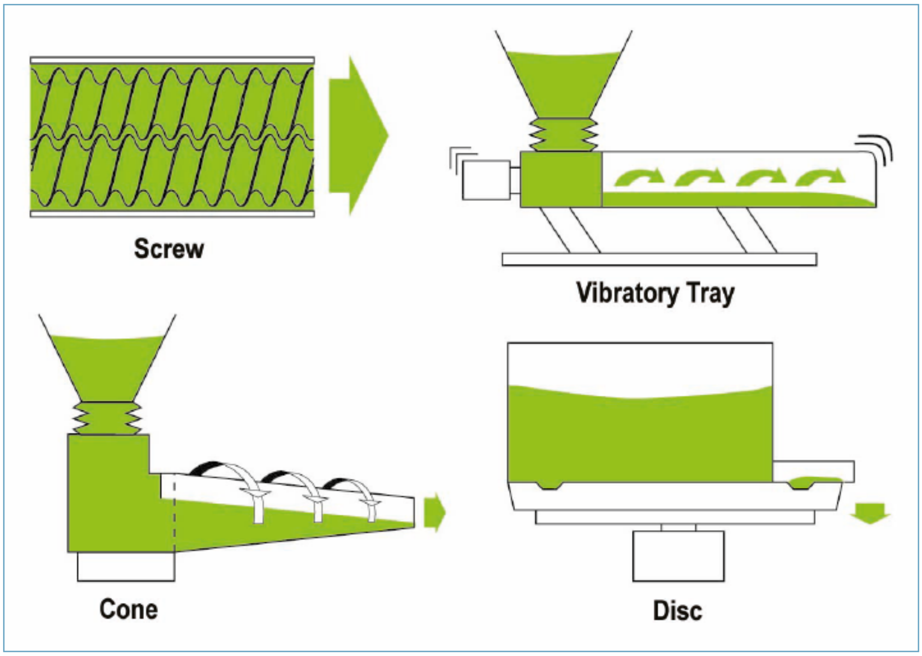

Figure 3 - Types of Microfeeders

technology have made continuous on-line microfeeding possible. Up to six weighments per second at resolutions of up to 1:4,000,000 are now possible, theoretically enabling the detection of a change in feeder-system weight on the order of a milligram. However, considering the application-dependent issues of feeder performance timescale requirements and the imperfect environment in which the feeder is likely to operate, basing a corrective control action on such a small-scale measurement is neither prudent nor required. A more feasible approach is to first isolate the feeding system as much as possible from the influences of its environment, and then accumulate successive weighments over a period judged sufficient to warrant confidence in the measurement, yet not so long that it becomes significant compared to the feeder's performance timescale requirements.

As mentioned at the beginning of this article, everything matters in microfeeding. Nowhere is this truer than in isolating the feeder system from its process environment.

Agents of measurement contamination include shock, vibration and other perturbations including drafts, and even convective air currents. Thus, microfeeders are often installed on carefully engineered tuned mass plates with additional shock/vibration isolators. Draft shields enclose the feeder to protect against airborne forces. Especially flexible inlet and discharge connections are used as required in sealed systems. Even the selection and routing of cabling cannot be overlooked as a source of unwanted force transmission. And finally, weighing systems that exhibit any significant deflection are inappropriate for use in microfeeding.

The meticulous measures taken to physically isolate the feeder comprise the first line of defense against environmental contamination. A formidable second line is taken up by sophisticated post-measurement filtering and processing techniques geared to extract meaningful weight data from the raw measurement signal.

Control System - For a loss-in-weight feeder to compute its actual discharge rate, it must compare that value to the desired rate (setpoint), calculate any required corrective motor speed adjustment and accurately determine the change in system weight between two discrete operating intervals. The controller's self-tuning software sets the interval time and the weight filter automatically, based on setpoint. It also measures the weigh noise and compares it to the setpoint and adjusts the weight filter and the control parameters accordingly.

Also of concern in the area of control are the issues of refill and perturbations. During refill, whether manually or automatically performed, the essential basis for loss-in-weight control – measurement of system weight – is unavailable. Where refill is performed quickly, the system senses the abrupt increase in system weight and simply regards the event as a perturbation. Its response is to hold metering speed constant at its most recent, pre-disturbance value, and maintain it there for at least the settling time of the weigh filter, or until it again senses the return of the expected decline in system weight, at which time it would automatically revert to gravimetric operation. To improve the response time during refill, the self tuning increases the weight filtering speed during and after refill. At the moment when it switches over to gravimetric operation, it dynamically lowers the weight filtering speed again.

Where refill is performed more slowly, such as may be the case when using a refill feeder or similar device, some systems offer real-time automatic adjustment of metering speed to compensate for material density changes experienced within the metering zone caused by headload changes during refill.

Metering System - Mechanically, microfeeder metering system design involves much more than simply miniaturizing a larger scale feeder. While microfeeders are physically small, considerations of material handling dominate their design. Designed to hold a relatively small supply of material, a loss-in-weight microfeeder's integral hopper is typically a vertical cylinder or, even more preferably, an inverted cone type (wider at its base) to promote continuous flow even for cohesive materials, which might otherwise exhibit a stick-slip action on the hopper wall. A slowly rotating vertical agitator prevents hang-up of less than fully free-flowing materials while a horizontal scraper, rotating directly above the screw trough or disc channel, helps assure a consistent fill of the metering element and near-complete emptying for cleaning. This design feature is of particular interest to any industry feeding high value minor ingredients, such as flavors or pharmaceutical active ingredients.

For screw-type microfeeders the solid (closed-flight) intermeshed twin screw approach is often most appropriate owing to the positive-displacement-type effect afforded by its advancing cavity design. A low screw pitch enables finer control and smoother discharge by enabling screw speed to be maximized for a particular feed rate. To minimize any discharge pulsing due to screw rotation, twin screws are set 90o out of phase and an appropriately sized screen mesh may be positioned at the end of the screws to further buffer the discharge. Given the possible choices of metering elements and their associated variations, careful testing and evaluation is recommended to assure the best match between material and metering element.

Once discharged from the metering element, attention must also be paid to assuring that 1) all the material arrives at its intended downstream destination and 2) it arrives at its desired rate. At such low rates, effects ranging from post-discharge air currents, in-line pressure differentials and electrostatic phenomena can come into play. Solutions exist to all these concerns, but they must be anticipated and evaluated before they can be remedied.

And finally, where safety, cleaning and contamination concerns are paramount, materials of construction, finish, corner radii, ease of accessibility and disassembly, explosion/hazardous area duty, self-emptying efficiency, process connections and wash down capabilities all require special scrutiny according to the application.

Conclusion

The development of precision microfeeding technology for powders and other small particle sized materials opens up new avenues of operation and efficiency improvements for processors working with very low proportion/feedrate ingredients. To realize its full promise, however, microfeeding requires that especially rigorous attention be paid to every aspect of feeder design and application. After all, in microfeeding, everything matters.

With hopper removed, this top-down view shows how Model MT-12's horizontal scraper consistently fills the feeder's twin screws

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