Engineering Study for the Feeding Operation Process of a Continuous Manufacturing Line

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Abstract — *The use of continuous operations in solid-dosage manufacturing is growing rapidly and bringing benefits within pharmaceutical industry. One of the benefits that the continuous operation provides is that the development process turns to be easier and faster than in a batch operation. When designing a continuous manufacturing operation process, one of the challenges is the ability to consistently and continuously feed a powder into the downstream process. Variability in the flow rate of ingredients fed from powder feeders can change concentration of the process stream and propagate throughout the system ultimately leading to out of specification product [1] [2]. An engineering feeder study was conducted to establish the baseline process operation for each of the components while evaluating different operational conditions to ensure accuracy of the feeding process. Please include a summary of results related to critical process factors and responses.*

Key Terms — *Continuous Manufacturing, Feeder, Gravimetric, Loss-in-Weight, Solids Dosage, Volumetric.*

INTRODUCTION

Continuous manufacture is widely used on many industries worldwide and it's being introduced into pharmaceutical industries because it saves time and money by eliminating batching tasks. One of main benefits of the Continuous manufacturing operations is that it can be operated in small facilities since all equipment will fit into one place. Equipment neither is nor to meet a bath size but to meet a given throughput. Therefore it Increases equipment Utilization and also provides the framework for closed loop control, while ensuring Quality Product. One of the first steps in continuous manufacturing process development is the ability to design and optimize the powder feeding operation to ensure a consistent and continuous feed a powder to the downstream process. For example, cohesion and changes in material density can cause variability in the flow rate of ingredients fed from feeders. This means that if, in a brief period of time, the feed rate of one ingredient changes with respect to the others, the change in concentration of the process stream can propagate all the through the system ultimately leading to out of specification product [1] [2]. While, this type of challenges can be mitigated by proper design of in-line blenders along the process stream, it is very important to understand which factors can affect accuracy of feeders [3]. Thus, to ensure adequate design and control of the upstream process (**Figure 1**).

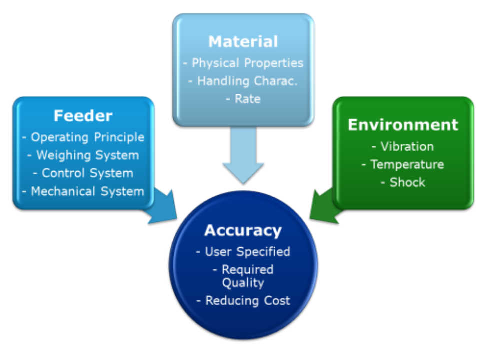

Figure 1
Key Aspects and Considerations for Loss-in-Weight Accuracy

RESEARCH OBJECTIVES

The main objective of this design project is to provide an overview of the optimization process of the feeders operation in a continuous manufacturing line to ensure adequate output control of the blend.

RESEARCH CONTRIBUTIONS

This engineering study is part of the supporting activities for the implementation of the Continuous Manufacturing Line. The execution of the feeding studies as well as the optimizations process is one of the main key aspects required to allow for a better process control in the downstream process.

RESEARCH BACKGROUND

This engineering feeder trials were conducted in a Solid Dosage Pharmaceutical Company located in Gurabo, Puerto Rico in collaboration with Academic Institutions in Puerto Rico and USA. Pre-developmental feeder studies conducted at the Academia was previously done to evaluate raw materials characteristics as well as the interaction with different Feeders and components configurations. Preliminary research work indicated that 1) raw material in general does not have constant density; as a result, mass flow rate variation as a function of the density of the material could affect the accuracy of the feeding (dispensing) and the hopper refill. Also refers that, 2) while the exact minimum refill level (refill point) is dependent on equipment and raw material properties, it was showed that refilling at levels between 60% and 80% of the hopper capacity did not presented an over chute in feeding rate. Therefore, as a result of this observations, Engineering feeder study was conducted to evaluate and understand similar effects on qualified equipment configuration and control loops selection when operated at different production feed rate (kg/hrs). Each gravimetric feeder will be raw material specific and should respond to individual material properties as well as to mechanical / electrical factors.

RESEARCH METHODOLOGY

As part of the engineering feeder study, four (4) gravimetric feeders corresponding to the API, Filler, Disintegrant and Lubricant were evaluated. The methodology used for this engineering run consisted of generating real time data (1 second frequency) of the feeding operation. This was done on each feeder individually by using a dynamic catch scale. The information gathered was further evaluated using statistical and mathematical (Fourier transformation) analysis to provide recommendation based on how feeding operations are performed. Additional runs were made after the initial engineering feeder runs to challenge feeder performance based on parametric aspects as well as setup conditions.

A brief description of the equipment and Instruments used on the feeder engineering run are depicted below and (**Figure 2**):

K-tron Volumetric Feeder

The K-tron volumetric feeders are part of the material feeding system of the continuous manufacturing process line. The raw materials of the drug product blend formulation are transferred pneumatically from the material room to a specific feeding system, composed of a volumetric feeder coupled to a gravimetric feeder. The material passes through an inline vibratory sieve and then to the volumetric feeder hopper. The material transfer to the volumetric feeder hopper occurs at a frequency determined by a level sensor in the volumetric feeder and the raw material use rate. The K-tron control module (KCM) controls the dynamic of transferring the material into the volumetric feeder as well as the synchronization of the volumetric feeder activity with the gravimetric feeder.

The volumetric feeders are used to refill the gravimetric feeder hopper during the volumetric feeding mode (refill cycle). When the amount of material left in the Gravimetric feeder hopper reaches the established minimum refill level (minimum hopper refill set point), the volumetric feeding mode (refill cycle) is initiated.

K-Tron Gravimetric Feeder

The gravimetric feeders are used to feed (dispense) each raw material of the product formulation into the continuous manufacturing process at the rate specified to obtain the desired drug product formulation. Each feeder is comprised of a material hopper and a motor / gearbox driven twin screw positive displacement feeding screw all of which is mounted on top of a weigh bridge. The KCM is responsible for coordinating the actions of the Gravimetric feeder.

Under normal operation the feeder has two operation modes: loss-in weight (LIW) feeding mode while feeding (dispensing) and volumetric feeding mode while refilling (refill cycle). The LIW feeding mode involves using the weight measured by the weigh bridge to determine the rate at which the material in the feeder hopper is decreasing and updating the screw speed to maintain the required control of the material feeding rate. When the feeder is running under LIW feeding mode it is emptying and will eventually have to be refilled. When the amount of material left in the feeder falls below a certain point (minimum refill level), a refill cycle is initiated and the feeder switch to volumetric feeding mode. When the gravimetric feeder reaches its maximum hopper capacity (maximum refill level), material refilling or addition is halted and the feeder is switched back to LIW feeding mode. During the volumetric feeding mode, there is no weight measurement by the weighing bridge [4].

K-Tron Feeding Screws

The feeding screw is one of the main feeder's components to ensure adequate feeding of materials. The screw types recommended are coarse for major components and fine for minor components.

Dynamic Catch Scale

A Dynamic Catch is the instrumentation that was used to collect independent weight data of the Gravimetric feeder dispensed material. It consists of a reference scale interfaced via proprietary software to a Portable Computer (PC). Generated data is stored in a PC and reported for evaluation. A catch scale is needed because the internal load cell measurements for different loss-in-weight feeders use filtering algorithms, which do not allow for accurate comparison between different feeders and tooling configuration [3].

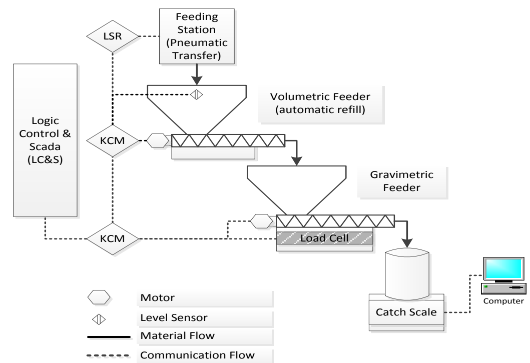

Figure 2
K-tron Feeding System Configuration (Automatic Refill Configuration)

Study #1: Gravimetric Feeder Hopper Capacity Evaluation and Feeder Trial Runs

Density of the raw material in the hopper can vary depending on how it was processed prior to being refilled or added to the hopper. Moreover, if the hopper is overfilled, the materials jam the feeding mechanism of the upstream volumetric feeder which would cause an addition force registered by the weigh bridge negatively affecting feeding performance.

Before trial runs, maximum hopper capacity of Gravimetric feeders was estimated by calculating how much material can fit in a hopper volume of 25 dm^3 using each raw material specific bulk density (**Equation 1**). This Full Hopper Capacity was then adjusted by a Safety Factor.

*Full Hopper Capacity (Kg) = K-tron Hopper Volume (dm^3) * Material Density (Kg/dm^3)* (1)

As a baseline, and to ensure an adequate hopper capacity (maximum refill level), each feeder hopper was fed to 90% of the hopper capacity and visually confirmed. (**Table 1Error! Reference source not found.**)

Table 1
Preliminary Optimal Hopper Capacity Evaluation

Material	Density Kg/dm3	Hopper Capacity (Kg)
API	0.61	13.7
Filler	0.49	11.0
Disintegrant	0.33	7.4
Lubricant	0.14	1.9

In order to evaluate feeder's operation accuracy in both gravimetric and volumetric modes, Feeder trial runs were made at different feed rates to meet proposed production rate criteria (40 – 60 Kg/hr). For consistency of test conditions, initial trial runs were completed using the gravimetric feeder control parameter "Tuning Method" set at "Normal" on all Gravimetric Feeders.

Recorded data from K-Sampler was exported in Excel CSV format and evaluated and graphed using Minitab Individual chart (I-chart) for visualization of the spread (or variation) of the data to 3 sigma (σ). I-chart upper and lower control limit (indicated by a red line) was then compared against operation criteria for each material operational feed rate. In addition, feeders feed rate and net weight data was exported from the control system in excel CSV format and used to graph actual feeder's operation behavior.

Study #2: Feeder Parametric Evaluation and Optimization Runs

During this stage of the engineering run, aspects related to parametric setting of the feeders as well as installation conditions were challenged. Similar to Study # 1, recorded data from K-Sampler was exported in Excel CSV format and evaluated and graphed using Minitab Individual chart (I-chart) for visualization of the spread (or variation) of the data to 3 sigma (σ).

RESEARCH RESULTS

Study #1: Gravimetric Feeder Hopper Capacity Evaluation and Feeder Trial Runs

Results from study # 1 were used to establish a baseline of each feeder with its associated material and to ensure adequate operation.

Prosolv HD 90 (Filler)

Prosolv HD90 is high-density silicified microcrystalline cellulose composed of 98% microcrystalline cellulose and 2% colloidal silicon dioxide and is one of the major materials of the formulation. During engineering runs for Prosolv HD90, Gravimetric Feeder feed rate set point was varied between 18.096 and 27.144 Kg/hr to meet production rate (line throughput) requirements of 40 – 60 Kg/hrs. Minimum refill level set point of 7.4 Kg (60%) and 9.8 Kg (80%) were randomly selected between trials runs for randomization purposes. Trial runs varied were made to allow for a minimum of two (2) automatic hopper refill cycle per test configuration.

At steady state (LIW or Gravimetric Mode), average feed rate as well as the overall variation was observed. High frequency variation on data points was mainly associated to experimental conditions and testing setup and not to the actual performance of the feeder (**Figure 3**).

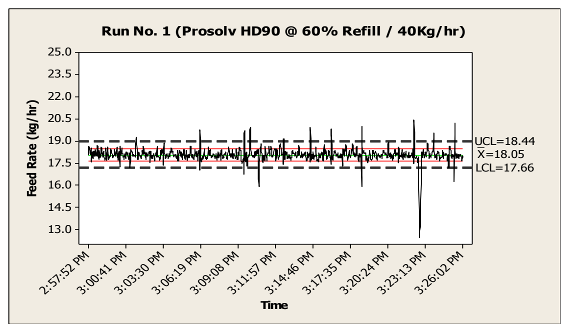

Figure 3

ProSolv HD90 Feeder Trial / K-tron Data at 60% Refill and 40Kg/hr.

From the control system data (**Figure 4**), Automatic refill operation (volumetric mode) was confirmed on both specified minimum refill level set points of 60% and 80%. Feed rate overshoot was observed at minimum refill level during hopper refill cycle (Volumetric Mode), but was concluded that observed effect on feed rate was associated to pressure buildup due to occluded filters installed on the Gravimetric Feeder hopper.

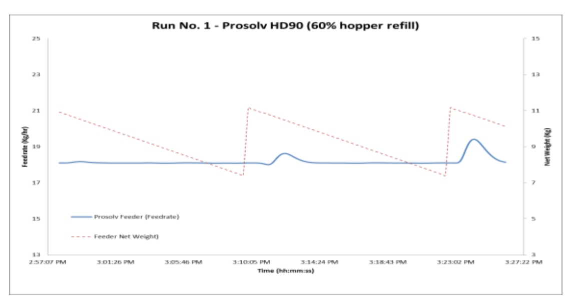

Figure 4

ProSolv HD90 Feeder Trial / Control System

Crospovidone NF / PH EUR (Disintegrant)

Crospovidone is one of the minor materials that act as a disintegrant in the process formulation. During trial runs for Crospovidone Gravimetric Feeder, feed rate set point was varied between 0.800 and 1.200 Kg/hr to meet production feed rate requirements of 40 – 60 Kg/hr. Minimum refill level set point of 5.0 Kg (60%) and 6.6 Kg (80%) were randomly selected between trials runs for randomization purposes. Individual runs were completed to allow a minimum of two (2) automatic hopper refill cycle per test configuration.

At steady state (LIW or Gravimetric Mode), average feed rate was found within established protocol criteria for both 40 – 60 Kg/hr production rates (line throughput) (**Figure 5**).

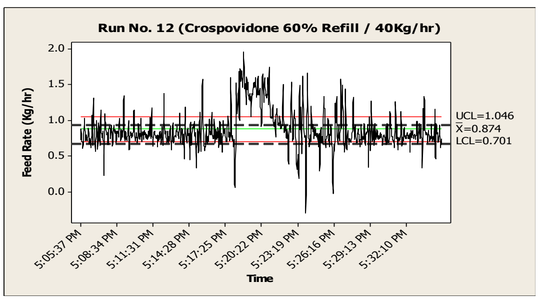

Figure 5
Crospovidone Feeder Trial / K-tron data at 60% refill and 40Kg/hr.

However, during the automatic refill operation (Volumetric Mode), overall variation was found outside established range criteria on most of the trial runs and data showed feeding sensitivity (overshoot) at 60% minimum refill level. This effect was also confirmed from the control system data, which showed feed rate, overshoot and undershoot conditions (**Figure 6**).

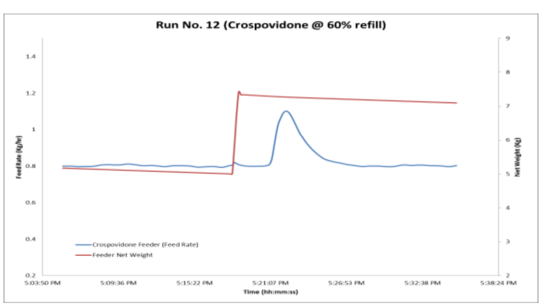

Figure 6
Crospovidone Feeder Trial / Control System

Magnesium Stearate (Lubricant)

Magnesium Stearate is one of the minor component materials that work as a lubricant in the formulation. During trial runs for Magnesium Stearate, Gravimetric Feeder feed rate set point was varied between 0.296 and 0.444 Kg/hr to meet production feed rate requirements of 40 – 60 Kg/hr. Minimum refill level set point of 1.3 Kg (60%) and 1.7 Kg (80%) were randomly selected between trials runs for randomization purposes. Individual runs were completed to allow for a minimum of two (2) hopper refill cycle per test configuration.

At steady state (LIW or Gravimetric Mode), average feed rate was found within established protocol criteria for both 40 – 60 Kg/hr production rates (line throughput) with better feeder performance (in terms of output control) at higher production feed rate (line throughput). However, overall variation was found outside established range criteria on most of the trial runs (**Figures 7 and 8**).

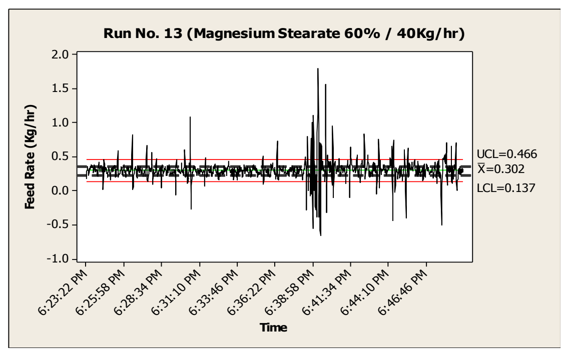

Figure 7
Magnesium Stearate Feeder Trial / K-tron Data at 60% Refill and 40Kg/hr.

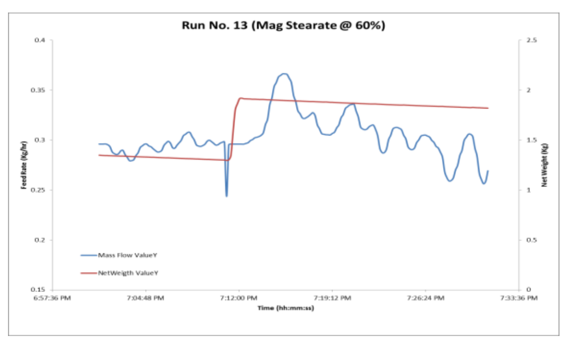

Figure 8
Magnesium Stearate Feeder Trial / Control System

Active Product Ingredient (API)

API constitutes 52.02% of the overall formulation. During trial runs for API Gravimetric Feeder, feed rate set point was varied between 20.808 and 31.212 Kg/hr to meet production feed rate (line throughput) requirements of 40 – 60 Kg/hr. Minimum refill level set point of 9.2 Kg (60%) and 12.2 Kg (80%) were randomly selected between trials runs for randomization purposes. Each trial run allowed a minimum of two (2) hopper refill cycle per test configuration.

At steady state (LIW or Gravimetric Mode), average feed rate was found within established protocol criteria at both 40 – 60 Kg/hr production rates (line throughput) with better feeder performance at higher production feed rate (line throughput). Overall variation was found within established range criteria. Automatic refill operation (Volumetric Mode) was confirmed with no feed rate overshoot or undershoot observed over minimum refill level range of 60 - 80% (**Figures 9 and 10**).

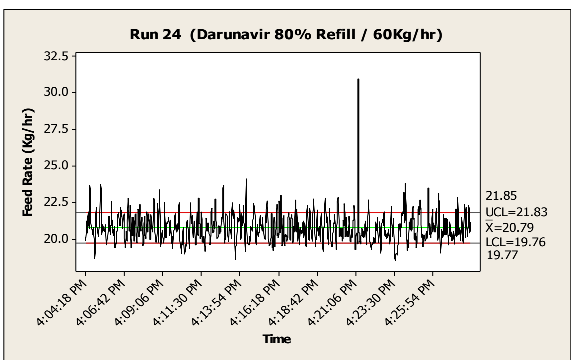

Figure 9
API Feeder Trial / K-tron Data at 60% Refill and 40Kg/hr.

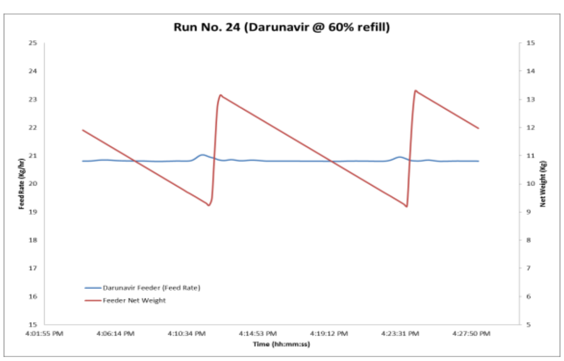

Figure 10
API Feeder Trial / Control System

Study #2: Feeder Parametric Evaluation and Optimization Runs

Tuning Method Control Parameter

Gravimetric Feeders control parameter "Tuning Method" set point was changed to evaluate the effect of control gain on feeder gravimetric loss in weight control. Control gain is the gravimetric response correction factor used by the Loss in Weight feeder software. The gravimetric control algorithm multiplies the control gain by the short-term mass feed error signal to determine the update to the feeder's motor speed or drive command. Thus, as the control gain increases higher, the drive command changes will be in order to maintain desired feed rate. **Table 2** shows K-tron tuning method parameter options available:

Table 2
K-tron Feeder Tuning Method Set Point

Tuning Method	Control Gain (%)
Very Slow	2
Slow	4
Moderate	8
Normal	15
Aggressive	30
Very Aggressive	50

Magnesium Stearate was used as representation of the worst case condition. Trial runs showed on **Figure 11**, indicates a reduction of approximately 45% in RSD% when changing the tuning method from "Very Slow" to "Slow" and somehow steady variation in terms of RSD% between the tuning methods selected from "Slow" to "Very Aggressive". That is that feeder's drive command will be able to physical control the screws to control feed rate to some extent, but it will mainly be driven by the physical properties of each individual material.

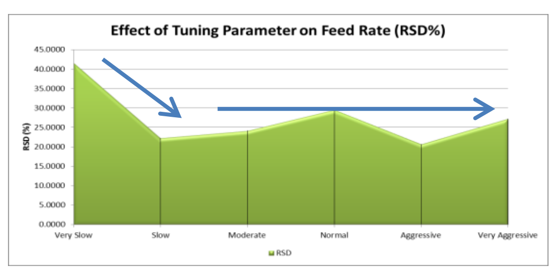

Figure 11
Effect of Tuning Parameters on Feed Rate

Feed Factor Calibration

Feed factor is defined as the relationship between mass feed and drive command. This value is used in both gravimetric and volumetric modes to determine the drive command response and provides an estimated capacity of the feeder with the material being metered. The feed factor is sensitive to material density, feed characteristics, and material handling in hopper. Therefore, any changes will be reflected in the feed factor value.

It is certain that after performing a feed factor calibration, feeder performance is expected to improve. However, this factor is directly related to the material properties, density and equipment condition at any given time. This was confirmed during trial runs using Crospovidone and Magnesium Stearate (Refer to **Figures 12 and 13**), were no direct correlation was observed by switching tuning method with and without performing feed factor calibration. However, as a manufacturer recommendation, it should be monitored to understand feeder response on changes with the material or process.

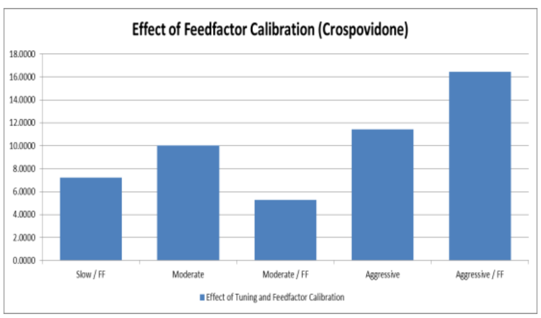

Figure 12
Effect of Feed Factor Calibration in RSD% using Crospovidone

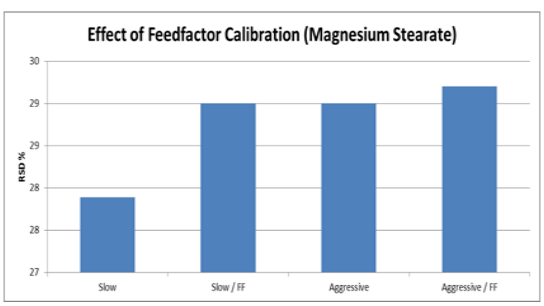

Figure 13
Effect of Feed Factor Calibration in RSD% using Magnesium Stearate

Adaptive Tuning "On vs. Off"

As defined by K-tron, "Pert" Value is a continuously updating, read-only, process variable that is calculated in both gravimetric and volumetric modes and it shows the amount of scale noise in the recent past. This value updates regardless of whether Adaptive Tuning is enabled or not. A lower number for the parameter Pert value is better. This means that with a 100% or greater value, the weight reading has more noise in it than expected weight loss based on the set point. A large "Pert" value is the result of scale weighing problems, pressure problems, cable and flexes frictions, as well as non-uniform material discharge. On a feeder perturbation, the motor speed remains steady – like in volumetric control – for a few updates until the proper weight signal reestablishes itself.

"Pert" detections are based on three things: 1) the feeder's set point, 2) the Adaptive Gain parameter, and 3) the most recent weight readings. The "Pert" detection software is self-adjusting if Adaptive Tuning is set to "On" because the Adaptive Gain decreases in tandem with increasing statistical variance in the weight signal. If Adaptive Tuning is set to "Off", then the Adaptive Gain parameter does not update, which makes the "Pert" detection system basically non-adaptive.

With the adaptive tuning off, overall RSD of approximately 35% as a result of the feed rate drifting as a function of time. Drifting was somehow more significant after performing an additional feed factor calibration. Both runs, "Pert" value did not exceed 100% and no perturbation issues on the equipment were observed.

Using similar condition mentioned above, the control gain was set to a value of "1" so the adaptive tuning on the feeder turned "On". An immediate reduction in feed rate variation was observed with an overall RSD % reduction of approximately 35% from previous runs. No perturbation issues observed over an extended period of time (**Figure 14**).

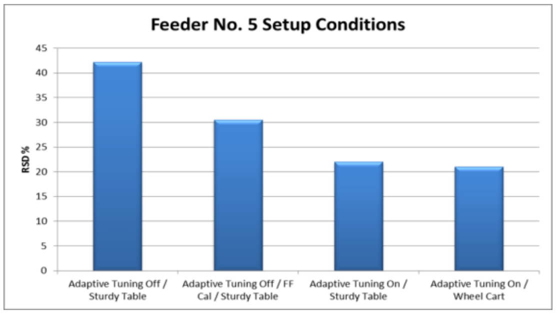

Figure 14
Feeder Setup Conditions Evaluation, RSD%

Feeder Installation Conditions

From the manufacturer technical articles, the development team confirmed those feeder installation conditions that affect the scaling system. It explained that any structure that holds the refill vessel or the tube that connects to the top of the refill or vent bellow is required to be stable. Therefore, following these recommendations to address high variation and source of perturbation, different feeder installation setups were evaluated.

Feeder Current State

Feeder was tested in its current state (vent filter installed and bellow with sanitary attachment). Feeder was operated at 18.096 Kg/hr and minimum refill levels were set at 60% of hopper capacity. Gravimetric Feeder perturbation was observed during both the hopper refill cycle operation (Volumetric Mode) and Loader Single Receiver (LSR) operation (volumetric feeder pneumatic refill). Feeder Perturbation (approximately 3 minutes) after refill operation resulted in feed rate spiking.

Vent Filter Occlusion

Additional runs without the use of a vent filter was performed. Feeder was operated at 18.096 Kg/hr and minimum refill levels were confirmed at 60% and 70% of hopper capacity. No overshoot / undershoot effect was observed upon removal of vent filter. However, feeder perturbation of approximately 30 seconds duration occurred after hopper refill cycle operation (during the LSR operation).

Reducer for Powder Transition

Bellow was then replaced by a reducer (**Figure 15**). This configuration eliminated any physical contact between the Volumetric Feeder and the Gravimetric Feeder.

Figure 15
Reducer Used during Feeder Installation Conditions

Feeder was operated at 18.096 Kg/hr and minimum refill levels were set at 60% of hopper capacity. No feeder perturbation was observed at steady state, after gravimetric hopper feeding, nor LSR operation (volumetric feeder pneumatic refill). Data measurement RSD% was reduced to approximately 33% on this configuration (**Figure 16**).

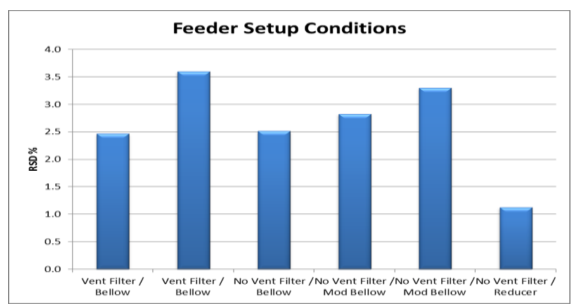

Figure 16
Feeder Installation Conditions Evaluation

Final Remarks and Optimization Runs

Some final remarks after the Feeder Optimization Activities are:

- Variation on the recorded data was associated to testing setup specifically on k-sampler material recovery location
- Adverse changes on feed rate were mainly associated to material aeration effect due to low bulk density material properties and

pressure buildup on hopper due to occluded filters.

- Changes of variations on feed rate were directly associated to material properties (low bulk density) combined with a low feed rate

Additional runs made on Prosolv HD90 Gravimetric Feeder at 60% minimum refill level during the feeder optimization activities. As observed in **Figure 17**, better feeder performance with a lowered feeding variation was achieved after eliminating filter occlusion and adjusting feeding system per manufacturer recommendations.

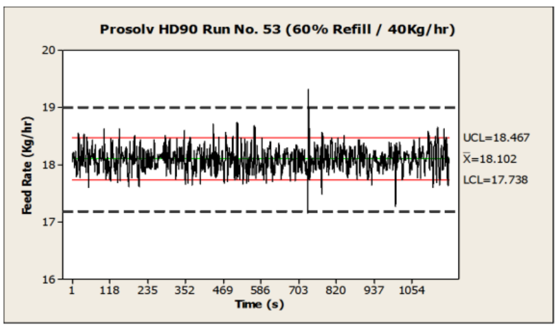

Figure 17
Prosolv HD90 Trial Run after Optimization Activities

For the Crospovidone Feeder optimization activities which included changing K-Sampler material recovery location and eliminating filter occlusion of vent filters, results showed better feeder performance with a lowered feeding variation was observed (**Figure 18**).

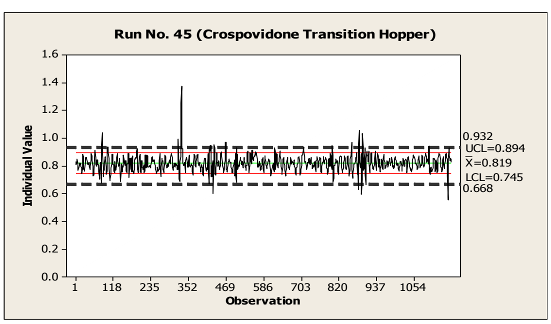

Figure 18
Crospovidone Trial Run after Optimization Activities

On the Magnesium Stearate Feeder, as observed in additional runs made during the troubleshooting activities showed that overall feeder performance (feed rate) is capable of feeding material to proposed average production criteria with a variation that is marginal to the established protocol criteria (**Figure 19**).

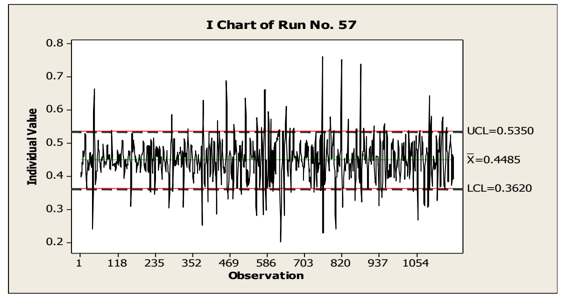

Figure 19
Magnesium Stearate Trial Run after Optimization Activities

Noise Effect Analysis of Feeders Data

While observed variation reduction is important for the process, expected performance of the blending process should be able to filter out the variation adequately. Variation filtration capability of the blending system provided higher assurance of the feeding adequacy at different throughput.

High frequency noise (variation) observed on feeder trial runs pose no effect on blend or tablet quality since the blender will act as a filter for such particular noise. The following mathematical equation was used to evaluate the effect:

Feeder Raw Data

The following equation represents feeder dispensed mass as a function of time:

$$f(x) = X\ (\text{mass, time}) \qquad (1)$$

RTD Equation Model

The following equation using dimensionless parameters to fit the expected residence time distribution of the blender.

$$C = \frac{X_2 * X_1^{\,0.5}}{(4 * \pi * theta)^{0.5} * e^{\left(-X_1 * \frac{(1-theta)^2}{4 * theta}\right)}} \qquad (2)$$

Where:

$$theta = \frac{\overline{time} - X_4}{X_3}$$

X1 = 41.3
X2 = 0.031
X3 = 23.1
X4 = 15.0

Fast Fourier Transform (FFT)

FFT Matlab algorithm is defined as the Discrete Fourier Transform (DFT) of vector X (any function vector). For length N input vector X, the DFT is a length N vector, with elements N;

$$X(k) = \sum_{j=1}^{N} x(j)\omega_N^{(j-1)(k-1)} \quad (3)$$

Where:

$\omega_N = e^{(-2\pi i)/N}$ Feeder raw data and RTD equation model data were individually evaluated in the FFT algorithm and the resultant vectors were multiplied to filter high frequency noise. Then, using the inverse DFT (computed by Matlab IFFT algorithm) of the resultant vector;

$$x(j) = (1/N)\sum_{k=1}^{N} X(k)\omega_N^{-(j-1)(k-1)} \quad (4)$$

Where:

$\omega_N = e^{(-2\pi i)/N}$ The resultant function vector represents the expected blender filtering capability.

As observed in **Figure 20,** selected feeder trial runs evaluated using the abovementioned method demonstrated the blender filtering effect. Noise from the feeder tends to be at a higher frequency as observed on the "green lines". As a result, the model predicts that the effect on the concentration at the blender will be minimal as observed in the "black lines". This supports that the blender filtering capacity should be adequate to manage the established feeder variation.

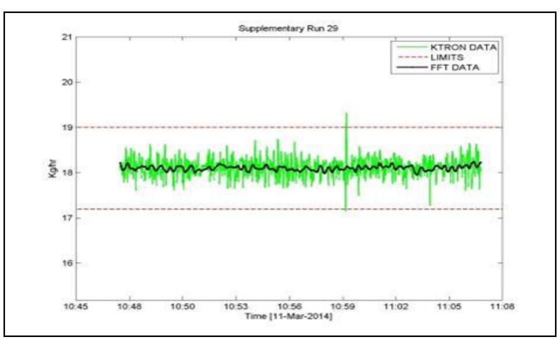

Figure 20
Prosolv HD90 Averaging Effect using RTD Model

CONCLUSIONS

Gravimetric feeder studies were conducted to (1) Determine K-tron maximum hopper capacity associated to each raw material, (2) Evaluate gravimetric feeder accuracy during Gravimetric Mode (loss-in weight (LIW)) and Volumetric Mode feeding operation (refill cycle) at different operational production feed rate (kg / hrs).

Studies were performed to evaluate source of variation associated with feeder parameters, testing setup conditions, external source of perturbation, Most of the recommendations to endure adequate feeder operations include but are not limited to:

1) Verification of vent filter conditions – Inspect for occluded vent filters. Occluded vent filter will limit hopper capacity to displace air during a hopper refill operation and will potentially increase the possibility of a feeder perturbation condition.
2) Verification of transition bellows conditions - Transition bellows used on the connection between the Volumetric and Gravimetric Feeders and Gravimetric Feeder to the Transition Hopper should be free from bends to reduce any force transmission between connecting points.
3) Ensure adequate feeder setup that includes a feed factor calibration prior to initiate operation
4) Reduce or control source of external perturbations in the platform area were the feeders are located.

Nevertheless, high frequency noise (variation) observed on most of the feeder trial runs will pose no effect on blend or tablet quality since the blender will act as a filter for such particular noise. Output generated data could be used for further evaluation (e.g. high frequency variation and smoothing effect).

No particular trend or recommendation on "tuning method" or feed factor calibration combination was established during trial runs. Manufacturer recommends performing feed factor calibration upon addition of new material into the hopper and/or upon observation of inadequate equipment response.

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