Engineering Management
Field Project

Conveying Cycle-Time Analysis in Pneumatic Conveying: A Study of Relationship between Batching & Convey Cycles in Powder & Bulk Handling Systems

By

Bahman Aghdaie

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____
Tom Bowlin
Committee Chairperson

____
Robert Zerwekh
Committee Member

____
Annette Tetmeyer
Committee Member

Date accepted:__________________

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I would also like to thank Karen Dare for her continued support of my work through creating this document.

Executive Summary

The purpose of this project is to develop methods for calculating the instantaneous convey rates for pneumatic conveying systems. Process and systems engineers are often faced with the question of calculating or verifying the required conveying rate for pneumatic conveying systems, based on the batching information, or the ingredient usage rates. The batching information usually comes in the form of spreadsheets describing different ingredients and their required weights in a recipe, as well as the number of required batches per unit time.

Due to time delays and other functions of the process, continuous conveying of the ingredients is not always practical. Therefore, the instantaneous convey rate is rarely equal to the ingredient usage rate.

There is no single methodology or formula that can be applied to all systems. That is probably why there are not many books or papers written on this subject. A few textbooks and articles describe the relationship between achievable convey rate, convey pipe size, ingredient physical characteristics, and convey distances, but hardly give any reference as how to find out what the instantaneous convey rate should be.

This paper includes five examples of pneumatic conveying systems. The first example discusses mixing cycle time for making a batch and calculates achievable number of batches per unit time. Discharge time is discussed

thereafter. The second example introduces a simple terminal use bin system. The third example discusses a multiple use bin system. The fourth example analyzes a multiple scale loop system. The last example is on the subject of loss-in-weight scaling. Dribble feed is discussed at the beginning of the last example. For each example a spreadsheet is created to solve each specific problem.

Chapter 1 - Introduction

Shick USA Corporation is a designer and manufacturer of automated bulk ingredient handling systems. A major part of the engineers' responsibility is making sure that the components of the system are sized properly to handle the specified production rates. The dry ingredients in these systems are conveyed through the pipe lines by pneumatic conveying, applying air pressure or vacuum.

There are many books written and much research done on sizing and designing pneumatic conveying system components such as blower packages, convey line sizes, and dust collectors. However, the design of these components always starts with a known instantaneous mass flow rate (LB/min or Kg/ hr), without mentioning how the desired mass flow rate is estimated or calculated.

Due to time delays and other functions of the process, continuous conveying of the ingredients is not always practical. Therefore, the instantaneous convey rate is rarely equal to the ingredient usage rate. Under-estimating the required instantaneous convey rate results in lower than desired production rate, and thus customer dissatisfaction and loss of future business. Over-estimating the convey rate, on the other hand, results in inappropriately upsizing the components of the system, resulting in a more expensive and uncompetitive system.

It is not always easy to see the relationship between the instantaneous convey rate and the usage rate (production rate). Detailed time analysis of system operation is required to obtain the instantaneous convey rate. The focus of this paper is analyzing the operation of some common systems and the relationship between desired production rates and the instantaneous convey rates.

Chapter 2 - Literature Review

In preparation of this paper an effort was made to find literature that discussed conveying time cycles and rates, and their relationship to batching and mixing processes. The ultimate goal of the author was to find textbooks that teach methodologies and discuss important factors in calculating the instantaneous convey rates. Pneumatic conveying systems are used in both food and chemical industries. There are also numerous pneumatic conveying systems used in the auto industry, camera and photography industry, and yes, the very familiar drive-thru banking industry! However, general and vague texts and articles could not be helpful. The author was looking for textbooks that were dedicated to the subject and discussed real problems and offered solution examples in detail.

A letter was written to American Institute of Baking (AIB) asking for information on this subject and any reference materials that they might suggest.
A PowerPoint presentation was received from Kirk O'Donnell, VP of Education of AIB International. The PowerPoint presentation mainly discusses the equipment sizing for handling dough, and suggests how an analysis of this nature would look. But there are no references to pneumatic conveying or convey rate analysis based on usage of a system.

In performing an internet search, the most difficult task was to find the right keywords to produce the desired results. Keywords in the following list are examples of what was used in doing research:

CYCLE TIME ANALYSIS
BATCH DISPENSING TIME ANALYSIS
BATCH PROCESS SIMULATION
BATCH PROCESS MODELING
BATCH PROCESS DESIGN
MATERIAL BALANCES
BATCH FORMULA
CONVEYOR TRANSFER RATE
TRANSFER RATE CALCULATIONS
FOOD PROCESS DESIGN
PROCESS ENGINEERING
MATERIAL PROCESSING TECHNOLOGY
MANUFACTURING SYSTEMS ENGINEERING
AUTOMATED MATERIAL HANDLING
CYCLE TIME CALCULATIONS IN BULK HANDLING SYSTEMS
MANUFACTURING SIMULATION
COMPUTER AIDED PRODUCTION ENGINEERING
THROUGHPUT ANALYSIS

An internet search led to an article in *Powder and Bulk Engineering* magazine, Sep. 2008 issue, titled "Minimizing Batch Error in Automated Batching" by Terry D. Fahlenbock, PE. This article discussed the basics of automated batching, definition of "pre-act" and its effects on batch error. Also, a second article in December 2007 issue of the same magazine titled "Automated Batching for Improved Product Quality and Process Efficiency", by David Boger, discussed advice on conveyor selection and integration of batching systems with plant equipment. This article included a few case histories.

Another internet search produced a simulation-software called "Flexsim". An impressive demonstration video and a free version of this software are available at www.flexsim.com. This software is claimed to be capable of producing a realistic presentation of any system. "Throughput Analyzer" at http://www.activplant.com/Products/ThroughputAnalyzer.aspx is another software that was found through the internet search.

"Proplanner" is a process time analysis software that was found at http://www.proplanner.com/product/details/timeestimation.aspx?gclid=CJWyifKGmJQCFQGbnAodw3XdBA .

In addition to the internet search, several textbooks were sought through the University of Kansas, Edwards Campus Library. *Weighing and Proportioning of Bulk Solids*, by Hendrik Colijn, 1983, discusses different weighing techniques, mechanisms, machinery, and control systems. It also describes the relationship between the feed rate and accuracy of weighing and provides examples of automatic batching calculations. The examples include cycle time calculations. However, the examples are based on mechanical type conveyors such as screw feeders and vibratory type feeders.

A textbook by Stanley M. Walas, *Chemical Process Equipment Selection & Design*, 1988, from the Department of Chemical & Petroleum Engineering, University of Kansas, describes different chemical process design methodologies. This book has more than 700 pages of comprehensive detail on a variety of chemical process equipment, with detailed formulas and calculation examples. Section 5 in particular, titled "Transfer of Solids", includes theory, empirical data, and example dilute phase pneumatic conveying calculations. Review of the above material has been interesting and informative; however, there were no results or direct references found in these papers that relate to the subject of this research.

Chapter 3 – Research Procedure

This field project was originated because of a real need in the engineering department for creating a systematic approach in calculating the instantaneous convey rates that meet the usage and the desired production rates of designed systems. Originally, creating a simulation or modeling software to do this job seemed ideal. However, it was soon determined that such an approach would be beyond the research time limit and would require advanced computer programming skills that could not be achieved by the author in a short time. Therefore, the original research approach was abandoned.

Researching the textbooks through University of Kansas Edwards Campus Library, and internet searches through Amazon and Google search engines, resulted in very few related texts, and these were very general. A few articles from *Powder and Bulk Engineering* magazine were studied and one in particular was purchased. The engineering manager and one of the sales engineers were interviewed on the subject. The AIB was contacted to see if they could provide any assistance. However, in the end the author had to rely mainly on his experience to create the approaches mentioned in this paper.

Five different examples were created and discussed, starting with an easy system example and increasing in complexity to further examples. Diagrams were created to clarify the systems and spreadsheet programs added for producing needed instantaneous convey rates.

Chapter 4 - Results

The objective of this research was to create tools to be used in finding the instantaneous convey rates quickly for various systems by inputting known parameters of those systems. Five spreadsheet programs have been created: Mixing Cycle Time for Making a Batch, Terminal Use Bin System, Multiple Use Bin System, Multiple Scale Loops, and Loss-In-Weight Feeder Scaling.

Mixing Cycle Time for Making a Batch (Figure 1)

Mixing cycle time depends on the number of ingredients to be mixed, the feed rate of each ingredient, the size of the batch, and the mixing process which dictates when each ingredient has to be added to the batch and how long mixing should continue.

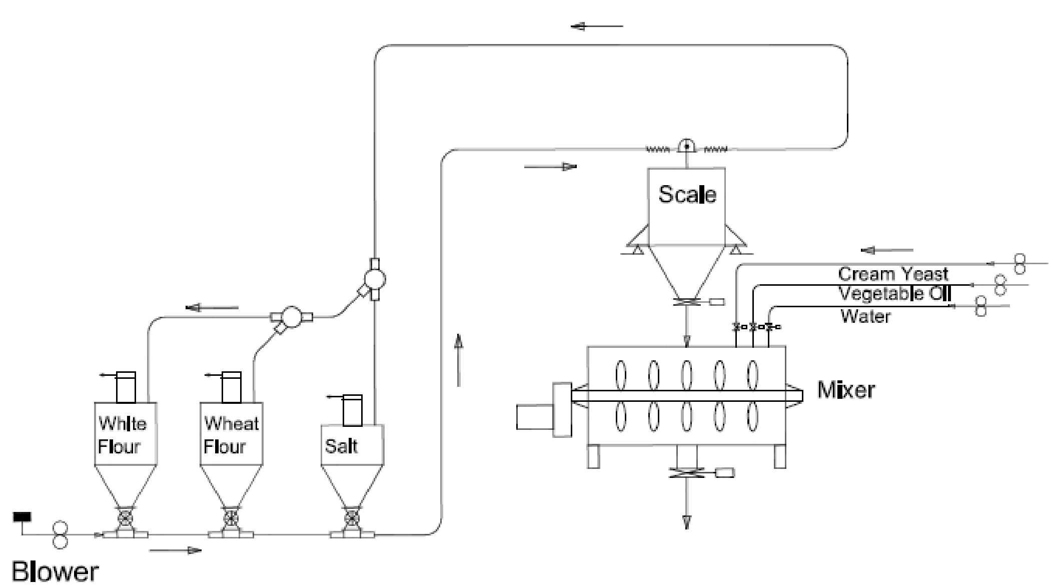

Figure 1 - Mixing Cycle Time

Example 1

White flour, wheat flour and salt are pneumatically conveyed to a scale hopper and dropped into a mixer one at a time through the same convey line. The convey line has to be purged for 30 seconds after each convey cycle to be able to convey the next ingredient. In addition to the dry powder ingredients, three liquid ingredients are added through 3 separate pipe lines connected directly to the mixer. The liquid ingredients - water, vegetable oil, and cream yeast - are not scaled but metered as they are being pumped.

The objective is to calculate the mixing cycle time and the number of batches per hour that can be produced.

The convey rates, the amounts per batch, and the process time sequence are shown below:

- Add white flour 250 LB / min, 750 LB / batch.
- Purge the convey line, 30 seconds.
- Add wheat flour 250 LB / min, 250 LB / batch.
- Purge the convey line, 30 seconds.
- Add salt 150 LB / min, 15 LB / batch.
- Discharge the above ingredients into the mixer. The discharge rate is 750 LB / min.
- Mix for 1 minute.
- Add cream yeast 100 LB / min, 50 LB / batch.
- Add vegetable oil 75 LB / min, 25 LB / batch, simultaneous with cream yeast.
- Mix for 2 minutes.

- Add water 250 LB / min, 375 LB / batch.
- Mix for 2 minutes.
- Discharge the mixer. The discharge rate is 500 LB / min.

<u>Solution</u>

To calculate the mixing cycle time we divide the weight of each ingredient in the batch by its feed rate to calculate the duration of its filling process. The dry ingredients are added one at a time, therefore, their filling times are added together. However, two of the liquid ingredients enter the mixer at the same time; therefore, whichever has the longer filling time has the dominant value.

The discharge time out of the scale hopper for the cumulative weight of the dry ingredients is calculated by dividing the total weight by the discharge rate. The discharge time out of the mixer is calculated the same way, except that it includes the weight of all ingredients in the mix including the liquids. At the end, the mixing times are added to calculate the total mix cycle time.

The spreadsheet for Example 1 is displayed on the next page.

Spreadsheet 1 - Mixing Cycle Time				
Transfer Rates:				
White Flour Transfer Rate	250	LB / min		
Wheat Flour Transfer Rate	250	LB / min		
Salt Transfer Rate	150	LB / min		
Scale Discharge Rate	750	LB / min		
Cream Yeast	100	LB / min		
Vegetable Oil	75	LB / min		
Water	250	LB / min		
Mixer Discharge Rate	500	LB / min		
Weighments:				
White Flour Weighment	750	LB		
Wheat Flour Weighment	250	LB		
Salt Weighment	15	LB		
Cream Yeast	50	LB		
Vegetable Oil	25	LB		
Water	375	LB		
Cycle Time (seconds)	**Start**	**Duration**	**Finish**	
White Flour Fill Time	0	180	180	sec
White Flour Purge Time	180	30	210	sec
Wheat Flour Fill Time	210	60	270	sec
Wheat Flour Purge Time	270	30	300	sec
Salt Fill Time	300	6	306	sec
Salt Purge Time			0	sec
Discharge Scale into Mixer	306	81.2	387.2	sec
Mix Time 1	0	60	60	sec
Cream Yeast Fill Time	60	30	90	sec
Vegetable Oil Fill time	60	20	80	sec
Mix Time 2	90	120	210	sec
Water Fill Time	210	90	300	sec
Mix time 3	300	120	420	sec
Mixer Discharge Time	420	175.8	595.80	sec
Total Mix cycle Time	595.80	sec	9.93	min
Possible Number of Batches / hr	6.042			

<u>Using the Spreadsheet Calculator as an Analysis Tool</u>

It is noteworthy in this calculation that as soon as the scale discharges the ingredients into the mixer, the discharge valve of the scale hopper closes and it is ready to receive the ingredients again. At the same time, the mixer starts its mixing function and receiving the liquid ingredients. Therefore, the mixing process and filling the scale hopper can start simultaneously after the first batch is in the mixer. Thus, either the filling time or the mixing time becomes the dominant time value of the cycle.

The spreadsheet calculator is set up to have a start time, duration, and finish time. At the end, it compares the two values of the total mixing cycle time versus the total filling cycle time and selects the larger value as the batching cycle time. To calculate the possible number of batches per hour, the number of minutes per hour (60) is divided by the batching cycle time in minutes. Using the spreadsheet, one can lower the convey rate for the white flour, for example, from 250 LB / min down to about 115 LB / min, at which point the scale hopper fill time increases and becomes equal to the mix time. This proves that the convey rate of 250 LB / min for white flour can in fact be reduced to 150 LB / min without changing the possible number of batches per hour. Using this analysis, the system can be optimized for efficiency.

Discharge Time

During the time that the scale is discharging product into the mixer, conveying to the scale hopper is not possible. The question is whether the discharge time should be included in the conveying cycle time calculation. The answer is that the discharge time is a factor if there is only one scale hopper in the system. However, if the convey system is feeding multiple number of scale hoppers, it can move on to the next hopper and need not wait for the scale to discharge.

The discharge time must also be included in the calculation of possible number of batches per hour as described in the beginning of this paper. In order to calculate the number of batches per hour, a time analysis of the mix cycle is required. Mix cycles include the scale fill time and discharge time for the system in question, as well as fill time and discharge time of other ingredients by other systems, which may or may not happen simultaneously, plus mix time and discharge time out of the mixer.

Accurate estimation of discharge time is a difficult task. Discharge time depends on the ingredient physical characteristics, hopper design and construction, and outlet shape & diameter, to name a few. Extensive research on this subject has been performed by a few scientists and theoretical and empirical formulas have been developed. Hendrik Colijn explains gravity flow in hoppers and bins and provides mathematical formulas for calculation of gravity flow rates out of the hoppers in his book *Weighing & Proportioning of Bulk Solids*.

Jenike & Johanson, Inc. have published papers on this subject that can be downloaded from their website at www.jenike.com. There are also discharge rate data published by a few manufacturers based on different class of products and outlet sizes that may be used for the purpose of time estimation.

Terminal Use Bin System (Figure 2)

This system is comprised of a pressure blower, an ingredient feeder, a sifter or screener, a use bin, and a dust collector. This type of system is usually used to transfer the required ingredient for one hour, one shift, or one day usage, from silos to a use bin inside the plant.

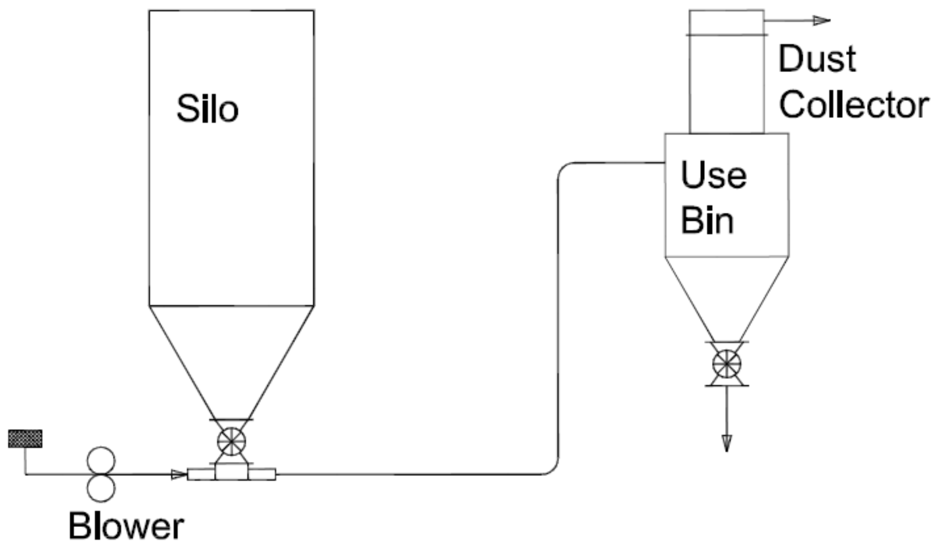

Figure 2 - Terminal Use Bin

Example 2

Characteristics of this hypothetical system are as follows:

- Usage at the use bin = 7,800 LB/hr = 130 LB/min.
- Use bin capacity = 7800 LB
- The Distance between the source feeder and the use bin is 300 ft.
- The product should be conveyed at 4500 ft. / min. velocity.
- The blower has to run for 5 seconds to stabilize the air flow in the pipe line before feeding the product into the pipe line. This can be referred to as “ramp-up” time.
- The blower will run for a few seconds, before it stops, to purge the convey line, after a high level signal is received.

What is the minimum convey rate to meet this usage?

<u>Solution</u>

For this type of system, the common practice is to size the blower to convey 45 minutes out of an hour to make sure the system stays ahead of the usage. Key calculations from the displayed spreadsheet below are:

System convey rate = 7800 LB ÷ 45 min = 173.33 LB/min

Required purge time = (300 ft) ÷ (4500 ft/min.) = 0.0666 min. = ~4 sec.

It is also important to calculate how long it takes to fill the use bin:

173.33 LB/min fill rate – 130 LB/min usage = 43.33 LB/min fill rate

7800 LB use bin capacity ÷ 43.33 LB/min = 180 minutes = 3 hrs

The blower will operate 5 sec stabilizing + 4 sec purging = 9 additional seconds, every 3 hrs. Even though 9 seconds is negligible in this case, the impact of this consideration will be shown in later examples.

Spreadsheet 2 - Terminal Use Bin		
Usage	7800	LB / hr
Use Bin Capacity	7800	LB
Convey Distance	300	ft.
Convey Velocity	4500	ft. / min
Start Delay	5	sec
Convey Time / hr	45	min
System Convey Rate	173.33	LB / min
Purge Delay	4	sec
Use Bin Fill Time	180	min
Additional Delay	9	sec

Analysis

The question in the previous example was finding the minimum possible rate. An arbitrary length of time (45 minutes out of an hour) was selected in the spreadsheet calculator to calculate the instantaneous convey rate. By increasing this time period, the convey rate can be decreased, until we reach the 60 minutes out of an hour, which produces the minimum possible convey rate. However, note that in this case a few seconds are calculated for ramp up and purge time, therefore, we can not quite use the full 60 minutes out of an hour for conveying. A convey rate of 132 LB / min is calculated versus the original 173 LB /min, if the blower conveys 59 minutes each hour.

Multiple Use Bins (Figure 3)

In this system multiple use bins are filled using a single convey system. Diverter valves enable the system to feed different use bins, one at a time.

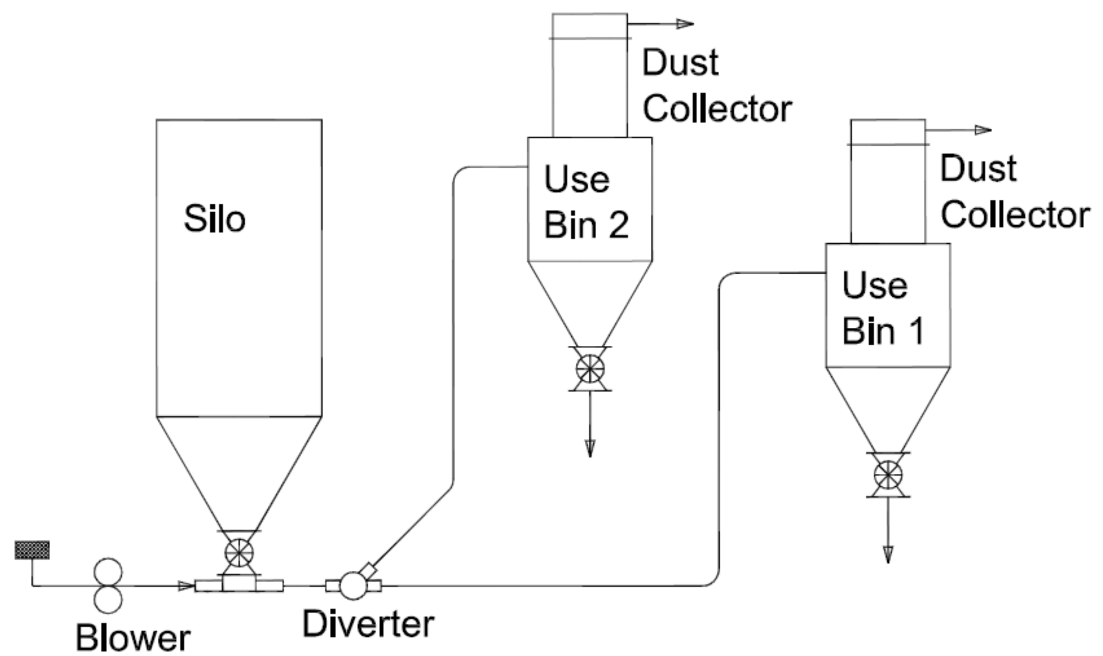

Figure 3 - Multiple Use Bins

Example 3

Characteristics of this hypothetical system are as follows:

- Usage at use bin 1 = 4200 LB/hr = 70 LB/min
- Use bin 1 capacity = 4200 LB
- Usage at use bin 2 = 3600 LB/hr = 60 LB/min
- Use bin 2 capacity = 3600 LB
- The distance between the source feeder and use bin 1 is 300 ft.
- The distance between the source feeder and use bin 2 is 400 ft.
- The product should be conveyed at 4500 ft/min velocity.
- The blower has to run for 5 seconds (0.0833 min) to stabilize the air flow in the pipe line before feeding the product into the pipe line (ramp-up time).
- The blower will run for a few seconds, before it stops, to purge the convey line, after a high level signal is received.
- The diverter valve design does not allow diverting until the convey line is purged.

What is the minimum convey rate to meet this usage?

Solution

We use the same approach as used in example 2. We allow the blower to run 45 minutes out of an hour. Key calculations from the displayed spreadsheet below are:

Total usage = 4200 LB/hr + 3600 LB/hr = 7800 LB/hr

System convey rate = 7800 LB ÷ 45 min = 173.33 LB/min

Purge time after filling use bin 1 = 300 ft. ÷ (4500 ft/min) = 0.0666 min

Purge time after filling use bin 2 = 400 ft. ÷ (4500 ft/min) = 0.0888 min

173.33 LB / min – 70 LB / min = 103.33 LB/min fill rate for use bin #1

173.33 LB / min – 60 LB / min = 113.33 LB/min fill rate for use bin #1

Time to fill use bin #1 = 4200 LB ÷ 103.33 LB/min = 40.64 min

Time to fill use bin #2 = 3600 LB ÷ 113.33 LB/min = 31.76 min

The time cycle for filling use bin # 1 is the sum of fill time and delay times for ramp-up and purging:

40.46 min fill + 0.0833 min ramp-up + 0.0666 min purge = 40.57 min

For the same reason the cycle time for filling use bin #2 will be:

31.76 min fill + 0.0833 min ramp-up + 0.0666 min purge = 31.91 min

Spreadsheet 3 - Multiple Use Bins			
	Use Bin # 1	Use Bin # 2	
Usage	4200	3600	LB / hr
Use Bin Capacity	4200	3600	LB
Convey Distance	300	400	ft.
Convey Velocity	4500	4500	ft. / min
Ramp-UP Delay	5	5	sec
Convey Time / hr	45	45	min
System Convey Rate	173.33	173.33	LB / min
Purge Delay	4	5.33	sec
Use Bin Fill Time	41	32	min
Total Delay	9	10.33	sec

Note that, in these examples, the filling and discharging happen simultaneously. The fill time is calculated with this assumption. That is why the convey rate (fill rate) should be reasonably higher than the use rate to be able to fill the use bins in a reasonable time.

The ingredient level in the use bin starts dropping after the use bin is full. The system starts filling when an empty signal received from either of the use bins. However, this may not be the best way to control this system, because in most cases an empty use bin is not desired. The low level sensors can be mounted where the use bin is half empty (mid-level sensor). This prevents the use bin from getting empty before the fill cycle starts.

Another method to prevent use bins from running empty is to use time cycles to fill them. For example, if it takes 2 hours to empty a use bin, start filling the use bin after 1 hour it has been feeding the system downstream. Caution should be applied not to create too many fill cycles, as the few seconds ramp-up and purge delays can add up and cause poor performance of the system.

Multiple Scale Loops (Figure 4)

In the scale loop systems the ingredient is returned (purged) back to the use bin as soon as the scale weight reaches a preset amount. This design allows the ingredient left in the pipeline to return back to the source instead of being added to the preset weight, thus causing scale inaccuracy. It also allows immediate change of fill cycle from one scale to the other if another scale is in queue for material.

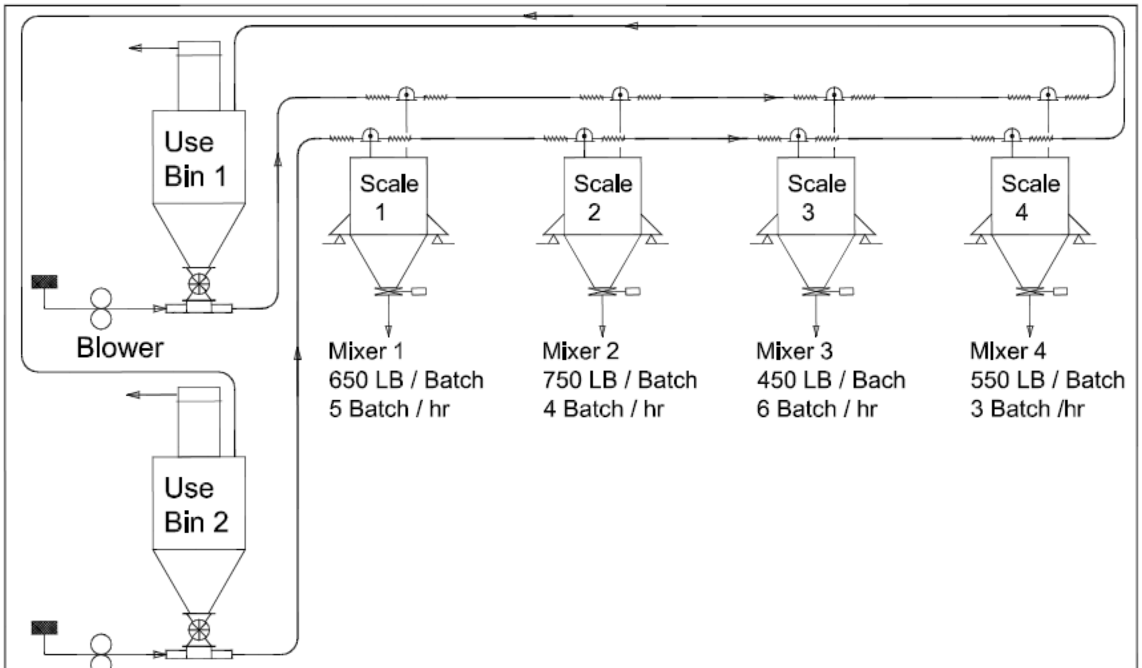

Figure 4 - Multiple Scale Loops

Example 4

Use bins #1 & 2 contain the same ingredient and are servicing four scale hoppers with different use rates. Each use bin has its own dedicated blower package which allows two scales to be serviced simultaneously. The use rates are as follows:

- Scale #1: 650 LB / batch, 5 batches per hour
- Scale #2: 750 LB / batch, 4 batches per hour
- Scale #3: 450 LB / batch, 6 batches per hour
- Scale #4: 550 LB/ batch, 3 batches per hour
- The total loop distance is 400 ft.
- Assume that purging is required after each fill.
- The system requires 5 sec. for ramp up delay.

What is the minimum convey rate to meet the demand?

<u>Solution</u>

As shown in the displayed spreadsheet below, we start by calculating the total usage:

Scale #1 usage = 650 LB/batch X 5 batch/hr = 3250 LB/hr

Scale #2 usage = 750 LB/batch X 4 batch/hr = 3000 LB/hr

Scale #1 usage = 450 LB/batch X 6 batch/hr = 2700 LB/hr

Scale #1 usage = 550 LB/batch X 3 batch/hr = 1650 LB/hr

Total usage = 3250 LB/hr + 3000 LB/hr + 2700 LB/hr + 1650 LB/hr = 10600 LB/hr

Total number of convey cycles (draws) per hour is the same as total number of batches per hour.

Total number of draws / hr = 5 + 4 + 6 + 3 = 18

Each convey cycle includes ramp-up time, convey time, and purge time.

Ramp-up time per cycle is 5 seconds. Purge time is equal to the loop distance divided by convey velocity.

Purge time per draw = 400 ft. ÷ 4500 ft / min = 0.0888 minutes = 5.33 seconds

Ramp-up plus purge time per hour = 18 (5 + 5.33) = 185.94 seconds = 3.01 minutes.

The discharge time out of the scale hopper is not considered as a factor in this example. The reason is that the convey system can service another scale hopper in the loop, while a certain scale hopper is discharging.

Maximum convey time available in an hour = 60 - 3.01 = 56.99 minutes

Minimum possible convey rate = 10600 LB ÷ 56.99 min = 186.29 LB / min

Since we have (2) systems the rate is divided between them.

Min. convey rate per system = 186.29 ÷ 2 = 93.15 LB / min

The spreadsheet calculator allows choosing a lower convey time than the maximum calculated. This is usually the case to make sure the system is ahead of the use rate and at times for future expansions. In this example 45 minutes convey time per hour is selected. As a result the actual convey rate is calculated to be: (10600 ÷ 45) ÷ 2 = 117.78 LB / min.

Spreadsheet 4 - Multiple Scale Loops			
Usage	LB / batch	batch / hr	LB / hr
Scale #1	650	5	3250
Scale #2	750	4	3000
Scale #3	450	6	2700
Scale #4	550	3	1650
Total		18	10600
No. of Draws / hr		18	
Ramp-up time / draw		5	sec
Convey Velocity		4500	ft / min
Loop Distance		400	ft
Purge time / draw		5.33	sec
Non-convey time / hr		3.1	minutes
Max. Convey Time / hr		56.9	minutes
No. Of Convey blowers		2	
Minimum Convey Rate		93.15	LB / min
Selected Convey time / hr		45	minutes
Actual Convey Rate		117.78	LB / min

Loss-in-Weight Feeder Scaling (Figure 5)

A Loss-in-Weight feeder is a type of volumetric screw feeder that is mounted on load cells. As the feeder feeds the ingredient, the load cells keep track of the lost weight. Once the desired amount for one batch is dispensed, the feeder stops.

It is common practice to slow down the feeder to about 20% of its normal speed when about 95% of ingredient is dispensed. This is called “Dribble Feed”.
A slower feed rate provides higher accuracy for the weighment and ensures that the dispensed ingredient weight does not exceed the set point.

A function called Pre-Act is also performed. Pre-Act is referred to the weight of the ingredient in transition right after the feeder is shut down. The Pre-Act is measured during the start-up of the system by trial & error. For example the feeder is shut down when less than 1% of the ingredient is remained to be dispensed. The remaining 1% will be dispensed after the feeder is shut down, since it is already in transition.

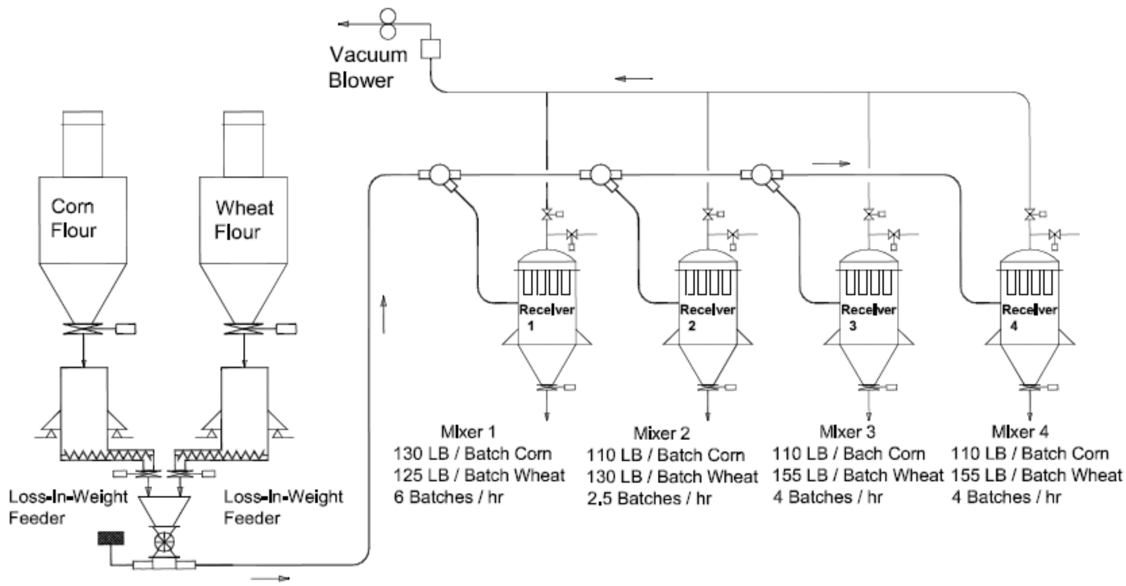

Figure 5 - Loss-In-Weight Feeder Scaling

Example 5

Two ingredients, corn flour and wheat flour are transferred to four mixers using two loss-in-weight feeders. The feeders simultaneously feed the ingredients into one converging hopper above a rotary valve that feeds a vacuum pneumatic convey system. Characteristics of this hypothetical system are as follows:

- Three diverter valves on the convey line distribute the ingredients to the four mixer receivers, one at a time.
- Purging of the convey system is required after each draw for the batch.
- Convey distance is 400 feet and the convey velocity is 4500 feet / min.
- There is a 5 second ramp-up delay at the beginning of the convey cycle.

What should the minimum convey rate be?

The batching information is given below:

- Mixer 1, (6) batches per hour

  130 LB / batch corn flour, 125 LB / batch wheat flour

- Mixer 2, (2.5) batches per hour

  110 LB / batch corn flour, 130 LB / batch wheat flour

- Mixer 3, (4) batches per hour

  110 LB / batch corn flour, 155 LB / batch wheat flour

- Mixer 4, (4) batches / hr

  110 LB / batch corn flour, 155 LB / batch wheat flour

<u>Solution</u>

Key calculations from the displayed spreadsheet below are:

Corn flour usage = 130 LB / batch x 6 batches / hr + 110 LB / batch x 2.5 batches / hr + 110 LB / batch x 4 batches / hr + 110 LB / batch x 4 batches / hr = 1935 LB / hr.

Wheat flour usage = 125 LB / batch x 6 batches / hr + 130 LB / batch x 2.5 batches / hr + 155 LB / batch x 4 batches / hr + 155 LB / batch x 4 batches / hr = 2315 LB / hr.

Compensating for the effect of dribble function, the feeders feed rates are estimated using the following method:

F = Feed rate, B = Batch weight, N = Number of batches per hour

Dribble function happens by running the feeder at 20% of its full speed for the remaining 5% of the batch. Therefore the dribble time can be calculated by the following formula:

Dribble feed time = 0.05 B ÷ 0.2 F

Normal feed time = 0.95 B ÷ F

Normal feed time + Dribble feed time = Total feed time = T

T = 1 ÷ N = Feed time per batch, hours

(0.95 B ÷ F) + (0.05 B ÷ 0.2 F) = 1.05 (B ÷ F) = 1 ÷ N

F = 1.05 B N

The value of (B x N) is the total usage calculated above. Therefore1.05 multiplier will be used to calculate the feeder rate for compensating for the dribble time.

Corn flour feed rate = 1.05 x 1935 LB / hr = 2032 LB / hr

Wheat flour feed rate = 1.05 x 2315 LB / hr = 2431 LB / hr

Total number of draws / hr = total number of batches / hr = 6 + 2.5 + 4 + 4 = 16.5

Ramp-up time per draw = 5 sec

Purge time per draw = 400 ft ÷ 4500 ft / min = 0.088 min = 5.33 sec

Non-convey time / hr = 16.5 (5 + 5.33) = 170.44 sec = 2.84 min

Max. convey time / hr = 60 – 2.84 = 57.16 min / hr

Min. corn flour convey rate = 2032 LB / hr ÷ 57.16 min / hr = 35.55 LB / min

Min. wheat flour convey rate = 2431 LB / hr ÷ 57.16 min / hr = 42.53 LB / min

Min system convey rate = 35.55 LB / min + 42.53 LB / min = 78.07 LB / min

The spreadsheet calculator allows calculating a higher convey rate by decreasing the allowable maximum convey time per hour of 57.16 min. In this example we have chosen 45 minutes convey time, thus calculating a convey rate of 94.44 LB / min versus 78.07 LB / min. This assures the capability of the pneumatic convey system to stay ahead of the usage. The loss-in-weight feeder rates originally estimated have to be pro-rated to meet the convey system rate.

Spreadsheet 5 - Loss-In-Weight Feeder Scaling						
Corn Flour Feeder						
Usage	Corn Flour LB / batch	Wheat Flour LB / batch	batch / hr	Corn Flour LB / hr	Wheat Flour LB / hr	Total LB / hr
Scale #1	130	125	6	780	750	1530
Scale #2	110	130	2.5	275	325	600
Scale #3	110	155	4	440	620	1060
Scale #4	110	155	4	440	620	1060
Total			16.5	1935	2315	4250
Feeder Rate to Compensate for Dribble Time --------------------->				2032	2431	
Scale #1 Dribble Time / hr	57.59	55.37	sec			
Scale #2 Dribble Time / hr	48.73	57.59	sec			
Scale #3 Dribble Time / hr	48.73	68.66	sec			
Scale #4 Dribble Time / hr	48.73	68.66	sec			
Total						
No. of Draws / hr			16.5			
Ramp-up time / draw			5			sec
Convey Velocity			4500			ft / min
Loop Distance			400			ft
Purge time / draw			5.33			sec
Non-convey time / hr			2.84			minutes
Max. Convey Time / hr			57.16			minutes
Min. Corn Flour Feed Rate			35.55			LB / min
Min. Wheat Flour Feed Rate			42.53			LB / min
Min. System Convey Rate			78.07			LB / min
Selected Convey time / hr			45			minutes
Actual Convey Rate			94.44			LB / min

Chapter 5 - Conclusions

Despite the author's hopeful start, researching on the subject of this paper proved to be difficult. One difficult task was to find the right title. Without the right title, finding useful materials in textbooks, or on the internet, was a matter of chance.

The spreadsheet programs that were created will help answer some of the questions on the subject. This paper might be one the few written on this subject and can only be considered as a starting point for doing more research in future. It is the author's opinion that a modeling software specifically tailored to do such analysis would be a more efficient tool.

Chapter 6 - Suggestions for Future Research

A few systems have been analyzed in this paper. A more in-depth review of various systems is required to be able to categorize different types of systems and make sure all possible scenarios have been included.

The best resource for such research is a company's project archives. Each project is comprised of several small systems. Flow diagrams of the past 50-100 projects can be collected and reviewed. The difficulty is that a basic knowledge of operational sequence and ingredient recipes are also required for each project to better understand the flow diagrams. Two systems may look identical diagrammatically but operate differently. An interview with the individual who originally devised the system can answer many questions. But finding the time for such interviews and refreshing the individual's memory on a year, or several years old project may be difficult.

Categorization of different systems by itself can be a topic for future research. Such research can provide a more solid ground and a better point of view for analyzing these systems and possibly creating a universal spreadsheet calculator, or other computer based analysis tool, that covers the majority of systems.

Creating each spreadsheet calculator can take between half a day to a week, depending on the complexity of the system. It is the author's opinion that much research and many development opportunities exist on the subject of pneumatic conveying time-cycle analysis. This research is best done by a team rather than an individual. Knowledge of food and chemical processing, pneumatic conveying, process control, and advanced computer programming will be required to create useful tools to help the industry.

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