Material Handling Systems

by Clifford J. Weinpel

Introduction

Industrial bulk material handling generally centers on moving pelletized, granulated, powdered or flaked material from storage to process. The methods for accomplishing this task break down into two basic categories, mechanical and pneumatic conveying. After this, the choices become somewhat more numerous and complex. Mechanical conveyors include belt conveyors, screw conveyors, vibrating conveyors, drag conveyors and other methodologies. For the purposes of this chapter, it is fair to say that mechanical conveyors are most used outside of the plastics industry.

There are a number of reasons why pneumatic conveying systems for pellet, granular, powder and flake plastic resins are used almost exclusively in the plastics industry, but three of these are key. First, pneumatic conveying systems are relatively economical to install and operate; second, they are relatively clean running and simple to maintain and third, they are flexible in terms of rerouting and expansion. These systems can be classified into five basic categories as shown in table 1. and of these, the most widely used application solution for conveying plastic pellets is the dilute phase system.

The most economical ways to accept delivery of plastic resin is in bulk quantities. Bulk shipment is usually by rail car or bulk truck, with rail car being the least costly. Most film extruders having access to a rail siding take advantage of the cost savings associated with rail car delivered resin. This is true even though the initial investment in a system to unload and store resin delivered by rail is higher than for resin delivered by truck.

This chapter will focus on the systems required for pneumatic conveying, storage and in-plant distribution of plastic pellets when delivered by truck or rail car.

	Dense Phase	**Dilute Phase**	**Medium-Dense Phase**	**Dense Phase**	**Air-Activated Gravity Conveyor**
System	Fan	Blower	Pump	Blow Tank	Airslide
Pressure Range	$\pm$20 in. H_2O	$\pm$7 psi	15-35 psi	30-125 psi	Fan type 0.5 psi (closed) 4-5 psi (open)
Saturation Ft^3 air/lb mat'l	vac: 10-30 pres: 4.5-13	vac: 3-5 pres: 1.0-3.5	0.35-0.75	0.1-0.35	3-5 cfm/ft^2
Mat'l Loading Lb mat'l/lb air	vac: 1.3-0.45 pres: 4.5-13.0	vac: 4.5-2.5 pres: 13.0-3.8	45-18	135-45	-
Air Velocity (fpm)	6000	4000-8000	1500-3000	200-2000	10 through diaphragm
Max Capacity (tph)	100	300	300	400	500
Practical Distance Limits (ft)	vac: 100 pres: 200	vac: 200 pres: 500	3000	8000	100 ft 6 ft drop/length 3-10 deg. slope

Table 1. Classification of Pneumatic Conveyor Systems (Source: Bulk Material Handling Handbook, by Jacob Frutchbaum, 1988)

Bulk Unloading and Storage

Most bulk trucks today are equipped with self-contained, pressure type, pneumatic unloaders. For the processor, this means that the only equipment required is a bulk storage silo properly equipped to accept bulk truck deliveries as shown in figure 1. The silo should be located as close to both the building and access area for the bulk trucks as possible. Bulk trucks are usually operated by a driver who has the responsibility for the unloading process after the processor accepts delivery and indicates the storage silo to be loaded.

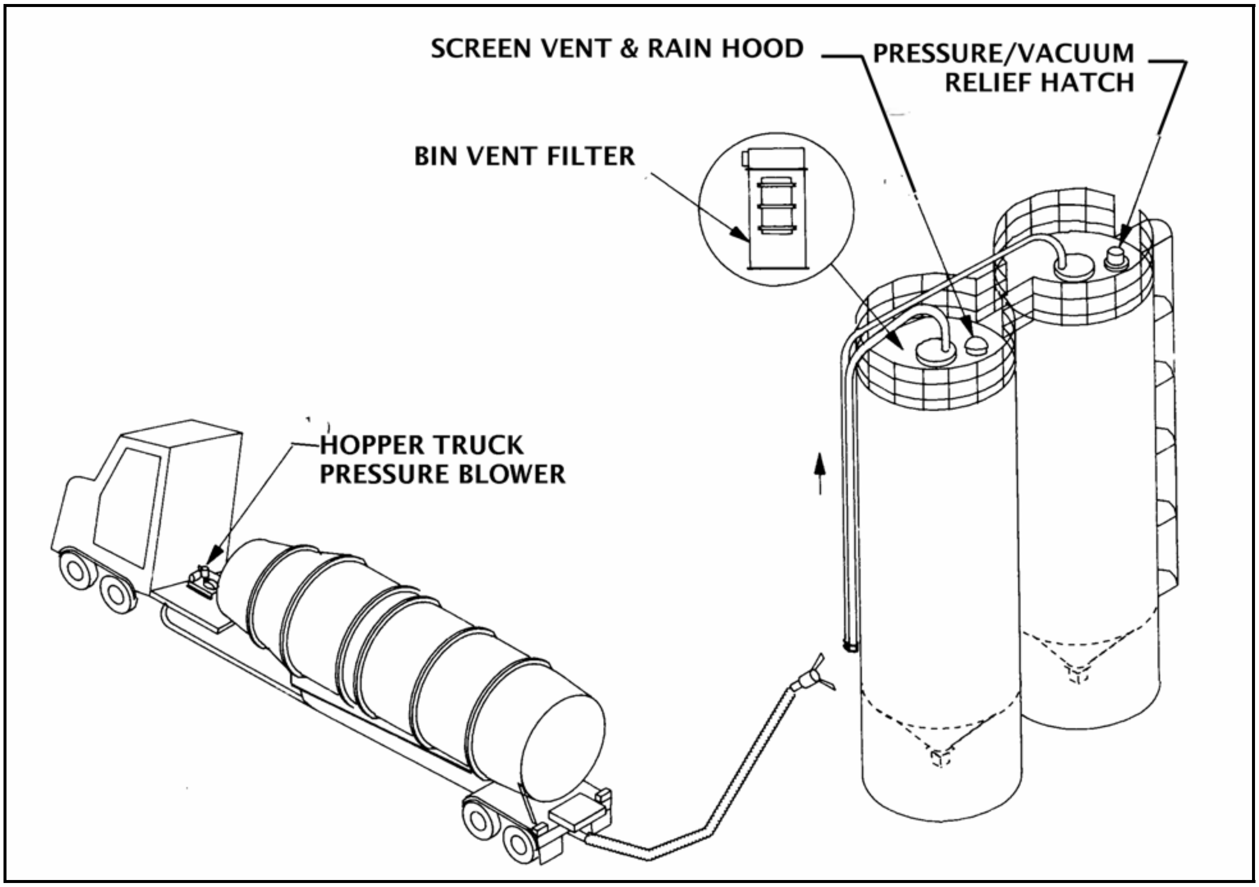

Figure 1. Pressure Delivery by Bulk Truck – Bulk trucks are commonly equipped with a pressure delivery system. A driver or operator will couple to a standard load line fitting and empty the truck into one or more silos. Conveying air is vented to atmosphere and in many cases filtered through a silo mounted static or self cleaning filter assembly.

Delivery by rail car requires additional equipment and manpower. A rail car does not come with its own unloader or the personnel necessary to accomplish the material transfer from rail car to storage silo. Bulk unloading of rail cars is most often done with one of two basic types of dilute phase material handling systems known as vacuum (pull) systems (figure 2) or combination (pull-push) systems (figure 3).

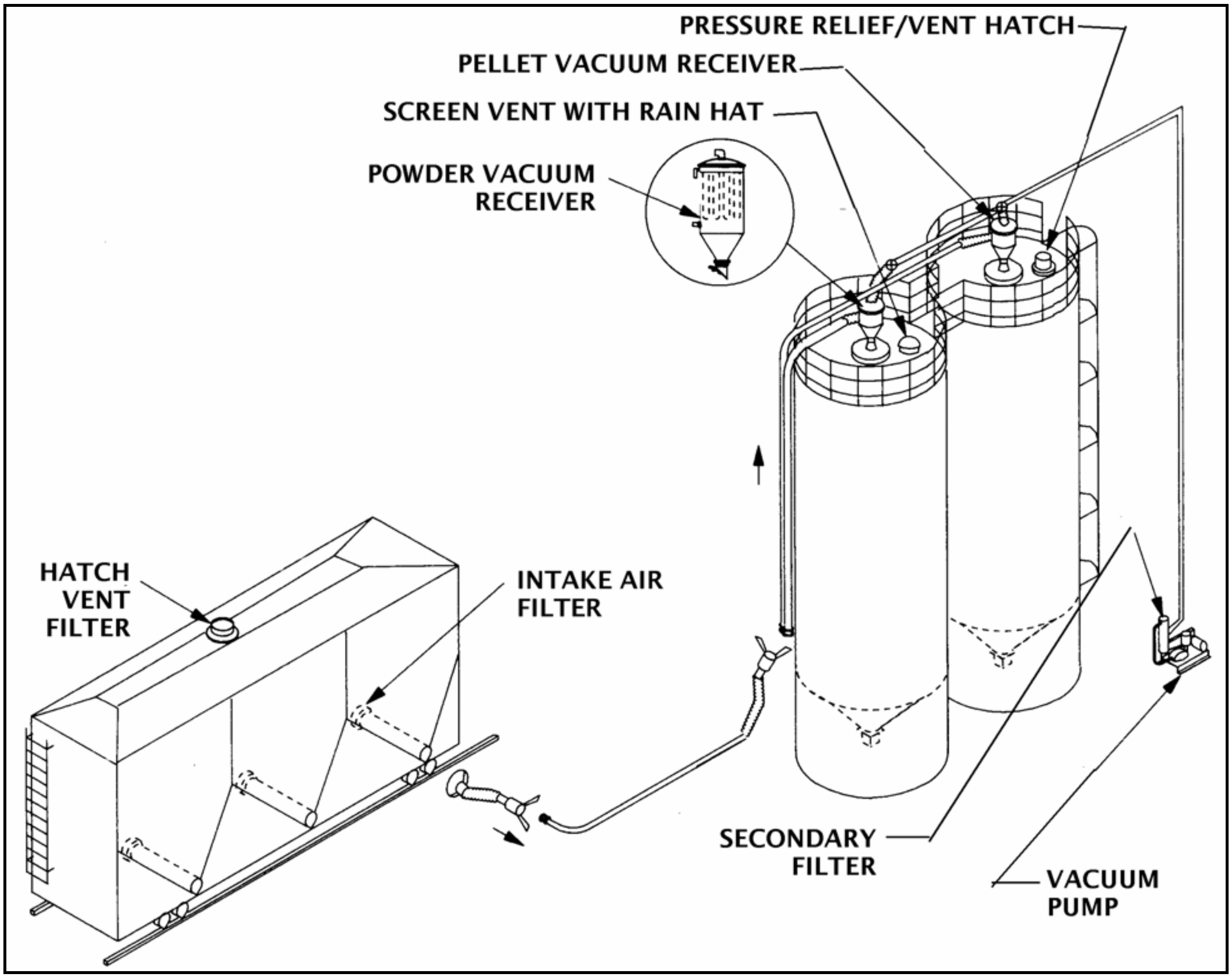

Figure 2. Vacuum (Pull) Delivery from Railcar – Material is drawn from each compartment of railcar using a vacuum pump and material vacuum receiver(s). Receivers can be "pump and dump" style with gravity operated discharge valves that periodically open when vacuum is removed and closed when vacuum is applied or "continuous loading" style that use a rotary valve for discharge.

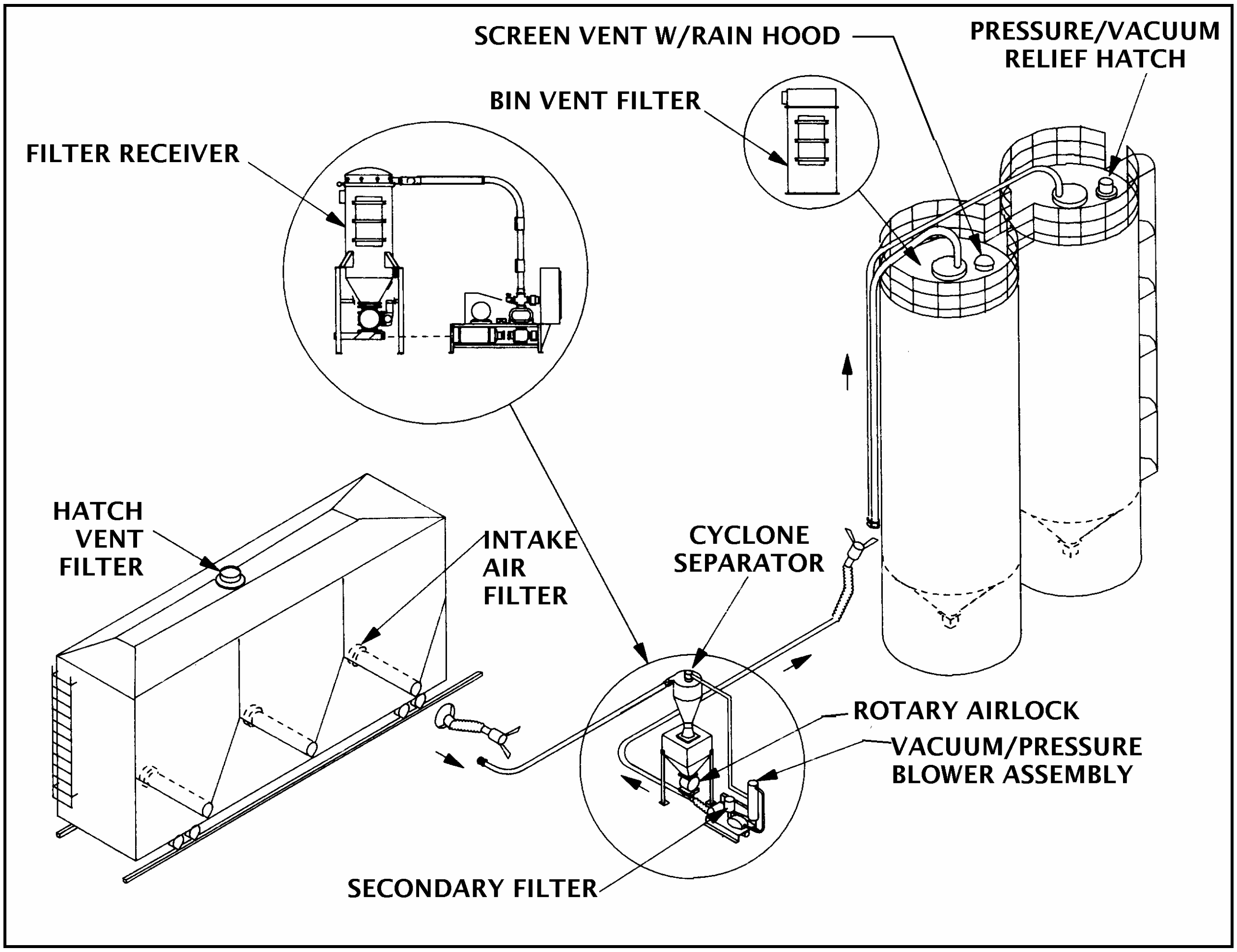

Figure 3. Combination Vacuum/Pressure (Pull/Push) Delivery from Railcar – Material is drawn from the railcar by the vacuum side of a pump assembly and transported by vacuum to a transfer station where it is dropped out of the conveying air stream and re-entrained in a pressurized air stream and conveyed by pressure to silos. The transfer station can be configured as a self cleaning in line filtered receiver or cyclone receiver with off-line air filtration.

The most frequently used of these is the combination (pull-push) system that draws the material out of the rail car by vacuum, passes it through a transfer station and blows it into the silo by pressure. The pull-push system is used most frequently because, for most applications, it is not possible or practical to attach a pressure system to a rail car and a vacuum system is not efficient for the distances, elevations and material transfer rates required to move material from rail car to storage silo. On the basis of the equivalent distances involved from rail car to silo and the required transfer rate, a pull-push system may include one positive displacement blower package using both the vacuum and pressure sides of the pump or two blower packages, one for the vacuum side of the system and one for the pressure side. A typical single pump rail car unloader specification is given in addendum "A." Typical bulk unloading systems with normal accessories are illustrated in figures 4 and 5.

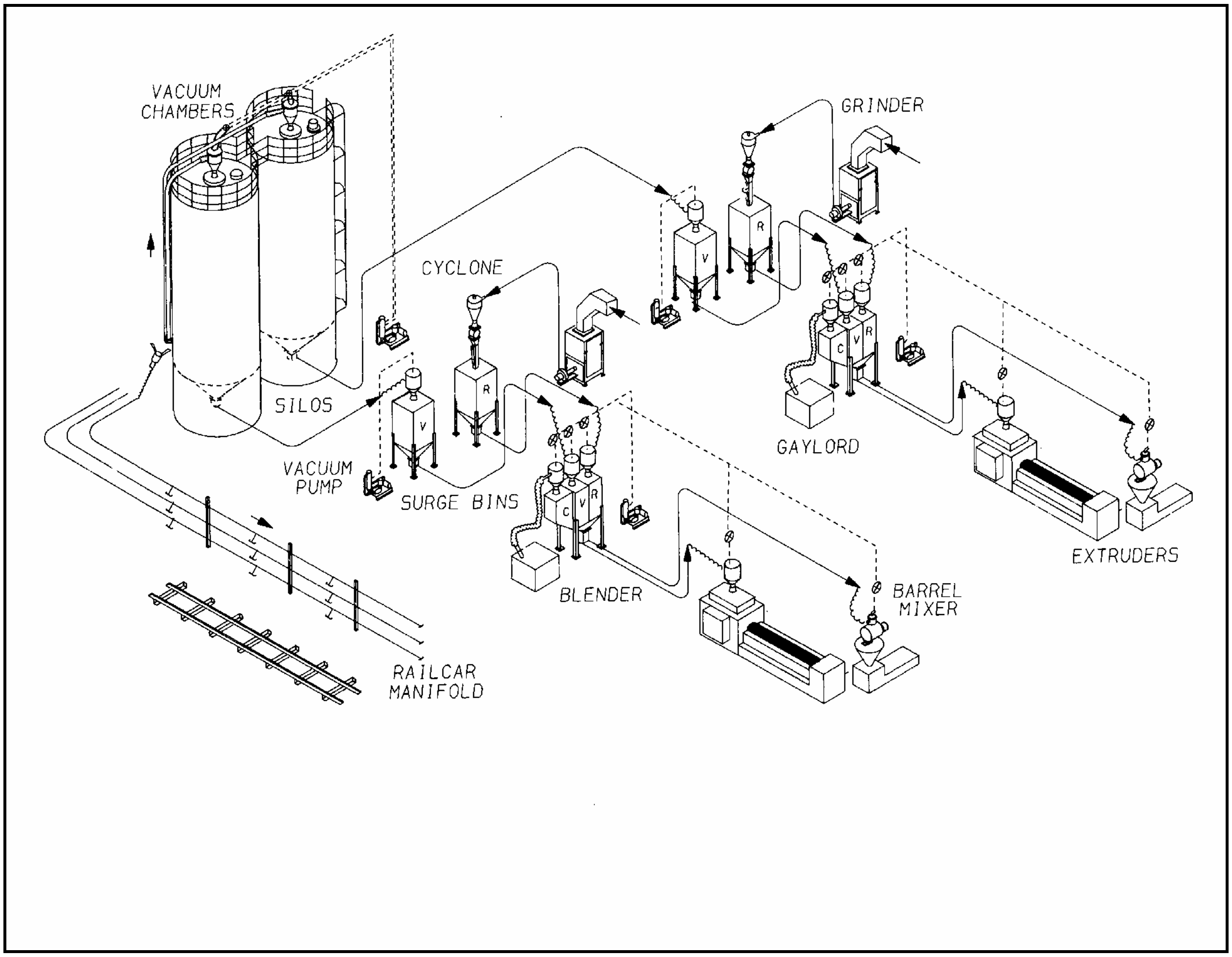

Figure 4. Typical Vacuum System for Railcar Unloading

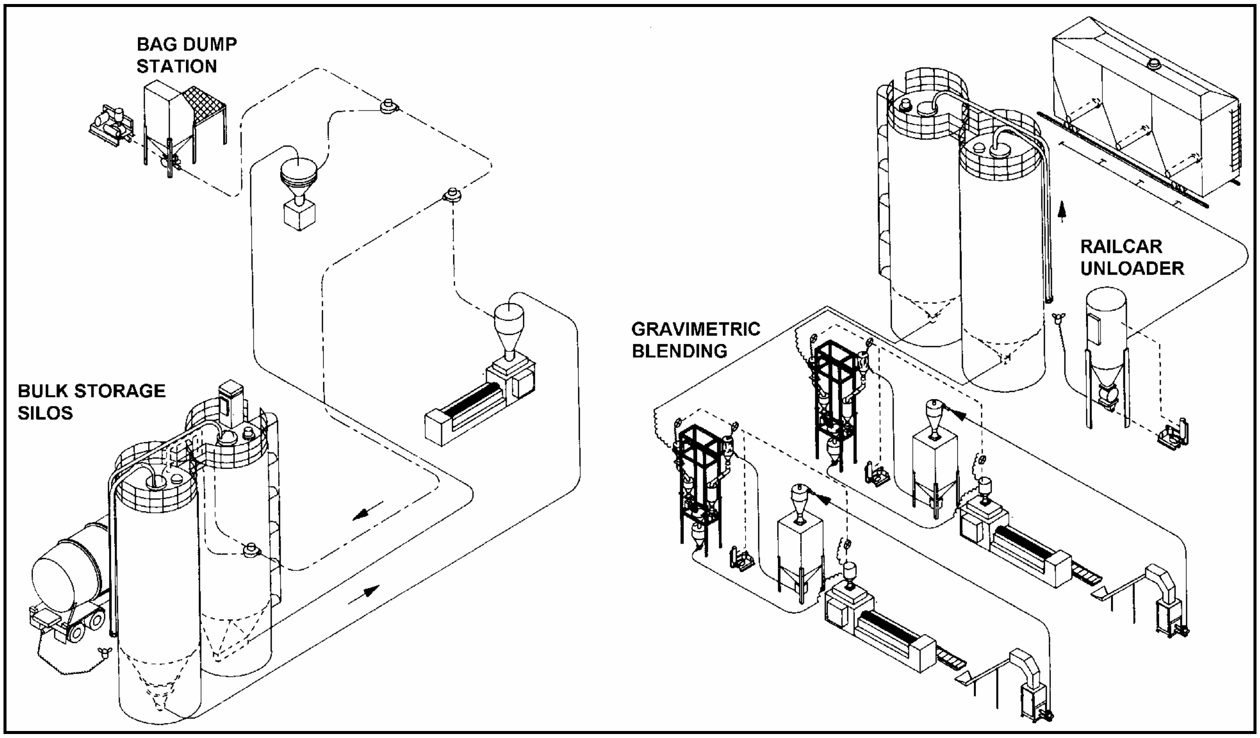

Figure 5. Typical Bulk Systems with Truck Delivery (left) and Railcar Delivery using Combination Vacuum/Pressure Unloader (right)

Manpower requirements for rail car unloading are not extensive but an operator is required on at least a part time basis. The operator must be trained in the proper methods for hooking up the rail car to the unloader and in the operation, troubleshooting and possibly maintenance of the unloader.

Silos are an integral part of the material handling system. Besides storing bulk resin, they are the link between the bulk material delivery system and the material distribution system. As such, they need to be equipped with components that allow both systems to function properly. Storage silos are available in a variety of capacities and types of construction. In the plastics industry, most silos are made from carbon steel, aluminum or stainless steel and are of welded, bolted or spiral construction. The most prevalent silo supplied to the plastics industry is the 12-foot diameter welded carbon steel silo in different heights and corresponding capacities. They can be equipped with a number of accessories, some of which are necessary and others that are desirable. A typical silo specification with accessories is given in addendum "B." It is important to note that all silos are engineered and certified to match the material to be stored and the geographic seismic location in which they are to be installed. A typical seismic location map is illustrated in figure 6.

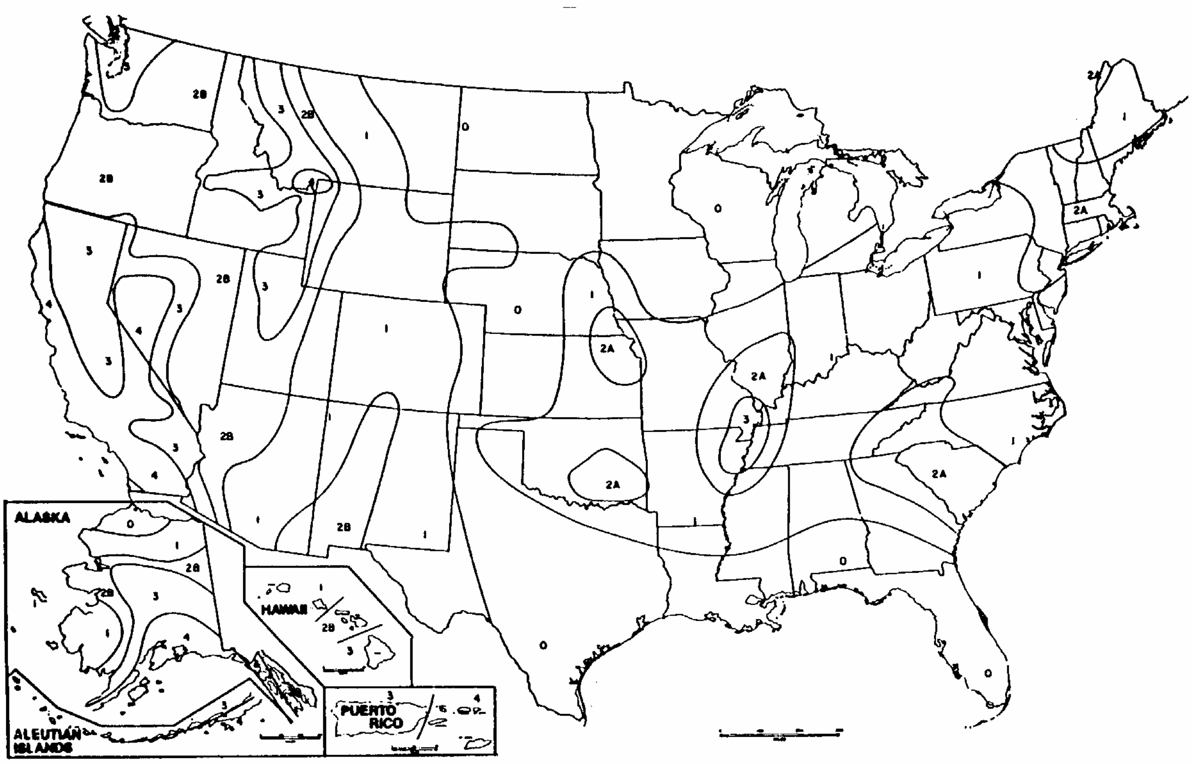

Figure 6. Typical Seismic Zone Map – Silos are engineered and fabricated for the specific zone in which they are to be installed. Installed silos should not be relocated without first identifying that the destination is in an equal or lesser rated zone.

In Plant Distribution

Material handling assumes different dimensions for in-plant distribution systems. Resin stored in outdoor silos must be brought inside the facility and distributed to the extrusion equipment. In some cases, this is a direct transfer from silo(s) to extruder hopper(s). In others, the material must pass through a number of intermediate pieces of auxiliary equipment before reaching the extruder hopper. A typical system may have material first transferred to inside storage bins, through metal separators and/or dedusters, on to dehumidifying or hot air hopper dryers then to blenders and finally to the extruders.

During this typical pre-processing route, the material must be conveyed in a way that all the necessary pre-processing functions are adequately performed. Additionally, the amount of mechanical degradation that the resin experiences in the form of fines, stringers and dust formation must be minimized and the material must not be contaminated or cause environmental problems.

To properly specify an in-plant, material distribution system, a complete study needs to be made of the process material requirements. At a minimum, one needs to know the following:

1. Material to be conveyed
2. Pre-processing operations necessary to meet plant production requirements

3. Degree of control required to meet operational requirements

Most material handling equipment and systems vendors will need detailed information about the system configuration and parameters to select the correct type and size equipment to be used. This is typically communicated through plant layouts, information surveys (see addendum "C" for a typical survey) and facility visits by systems engineers.

Material transfer from silos to in-plant equipment is accomplished with pressure, vacuum or combination type systems. In practice, pressure or combination systems are rarely required or used for in-plant, plastic pellet distribution systems. Vacuum systems are used almost exclusively, primarily because:

1. Most distribution systems are multiple supply/multiple destination that are best handled using vacuum conveying solutions.
2. Vacuum systems generally require less capital investment than pressure or combination type systems.
3. Vacuum systems are inherently cleaner operating than pressure systems because any small leaks in the system integrity draw clean air into the system rather than forcing dust laden conveying air into the plant environment.

To remove plastic resin from a silo a distribution box or vacuum tray adapter (VTA) is installed at the discharge of the silo. This VTA allows one or more distribution lines to be connected to the silo and brought into the facility. In the simplest system, the material supply line is routed past each extruder that will use material from the silo. In practice, a careful analysis of the present and future plant layout is necessary to determine which of many possible routing schemes will be used for the distribution piping.

Storage bins are frequently located inside the facility to provide an in-plant surge capacity for the distribution system. This is especially true if the plant location is such that the outside environment is subject to large seasonal variations in temperature and the extrusion process requires material at a relatively consistent temperature for process stability. Inside storage bins of sufficient volume, commonly called day bins, allow resin temperatures to stabilize before processing. Inside storage bins are also necessary if the system distances and throughput requirements would require the system conveying lines and pump sizes to be prohibitively large if conveying were direct from silo to destination. The inside bins are located between the silos and the distribution system and are typically loaded by a conveying system separate from the in-plant distribution system. Accessories for inside surge bins are similar to those for silos. Addendum "D" is a specification for a typical indoor storage bin.

The pivotal piece of equipment in a resin handling system is the power unit, frequently referred to as the blower package, vacuum loader, fan package, turbo blower, etc. Regardless of the terminology, this is the motive force producer for the dilute phase pneumatic conveying system. Two basic types of power units are commonly used for resin conveying systems, the positive displacement blower and the centrifugal or regenerative blower. Positive displacement blowers are used in both vacuum and pressure conveying systems. Centrifugal blowers are used most often in lower throughput vacuum conveying system. In centralized system applications, positive displacement blower packages are used almost exclusively. This is because of their ability to produce the volume of conveying air, measured in cubic feet per minute (CFM), at the higher pressures, measured in pounds per square inch (PSI), or vacuums, measured in inches of mercury (IN-HG). These operating characteristics are needed for the relatively high material throughputs and longer total conveying distances common in a centralized system. Manufacturers design systems with positive displacement blower packages sized to handle the conveying parameters of the system. Material to be conveyed, distance to be conveyed, pipe sizes, number of pipe bends, vertical lifts, allowable material velocities and energy losses are all included in the calculations used to size the blower packages. Because there are no defined sets of equations for mixed gas/solids flow, these factors are used in empirically derived charts and tables each manufacturer has developed through testing and experience for different materials and system configurations. A typical capacity graph for a vacuum conveying system selection is shown in figure 7. Processors normally provide the manufacturer with the material specification, the conveying distances and throughput requirements as part of the plant survey. The manufacturer performs all the necessary calculations and sizes the power units to meet the required operating parameters.

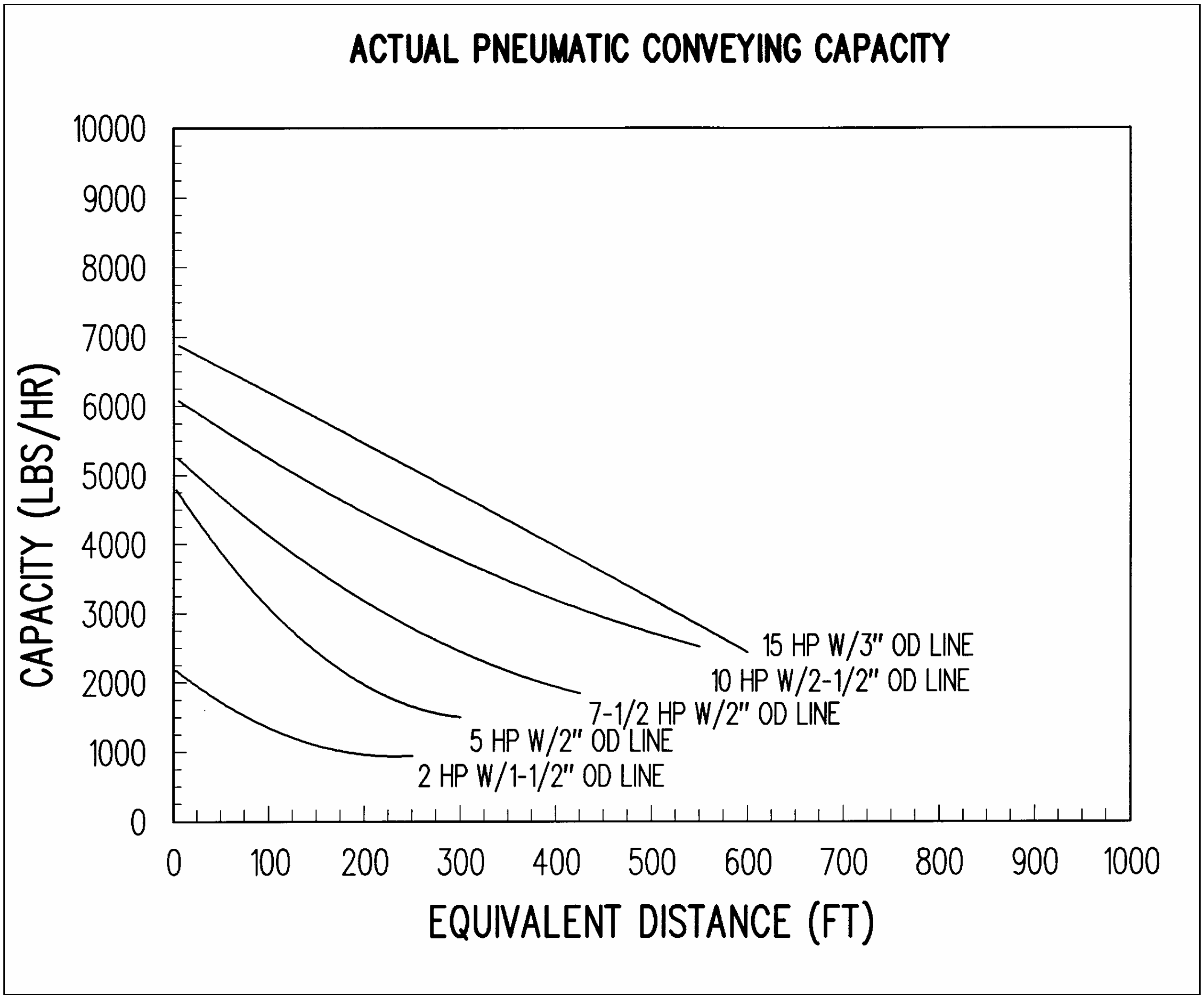

Figure 7. Typical Pneumatic Conveying Capacity vs Distance Graph for Various Size Vacuum Pumps – Equivalent distance is actual conveying distance factored to allow for parameters such as vertical rise and changes in direction of piping runs. Graphs of this type are helpful in preliminary sizing of pneumatic conveying systems with common parameters.

Whenever a vacuum conveying system is utilized for material transfer, a vacuum receiver is required at each drop off or destination point. Figure 8 illustrates two different vacuum receivers configured for different materials and conveying conditions. The basic vacuum receiver for plastic pellets is a simple device that should require little or no periodic maintenance. This is the most prevalent type of receiver used in the plastics industry and is all that is necessary for most systems. Vacuum receivers come in a range of sizes that are used by system suppliers to match the conveying system parameters.

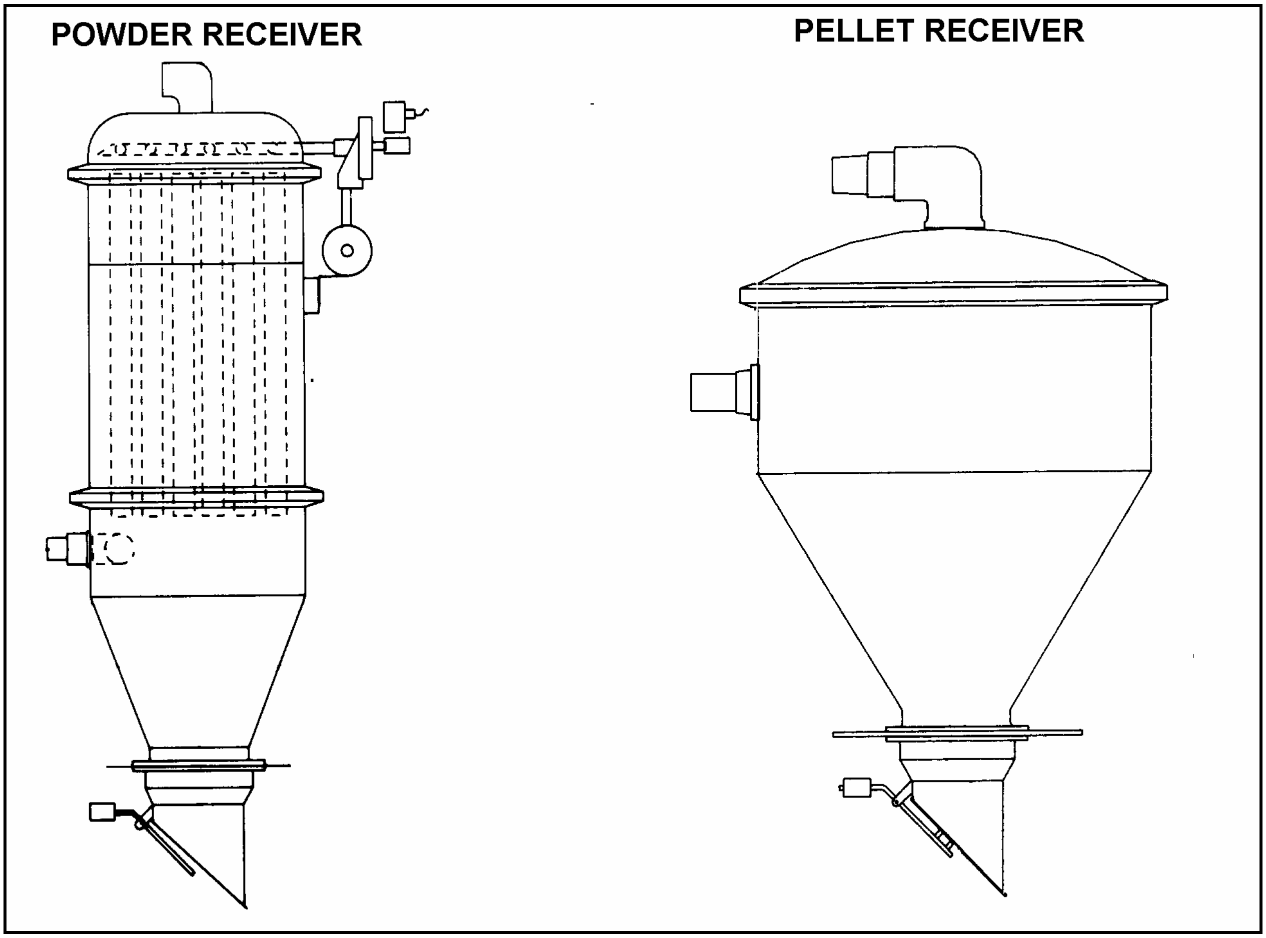

Figure 8. Typical Vacuum Receivers – A powder receiver is normally equipped with integral, self cleaning filtration which is also a good choice for materials laden with dust and fines. A pellet receiver is normally equipped with a coarse pellet filter which is usually more than adequate for most plastic pellets.

When the material being conveyed is heavily dust laden or is a granular or powdered material, the vacuum receiver is equipped with optional features to minimize the amount of particles carried back to the central pump protection filter. At times, equipment and systems vendors provide filters inside vacuum receivers to keep dust, granules or powder in the process flow. The degree of filtration required is based on the degree of fine particulates being conveyed. Higher amounts of fine particulates require a larger filter area per volume of conveying air. This is expressed as an air-to-cloth ratio in Cfm/Ft^3. Dust laden and granular materials such as linear low density polyethylene (LLDPE) rarely requires filtration in vacuum receivers whereas powdered resins such as polyvinyl chloride (PVC) frequently requires filters with air to cloth ratios of 10:1 or more. The processor should be careful when selecting vacuum conveying equipment that utilizes vacuum receivers equipped with filters. These are generally much more difficult and costly to both operate and maintain. They should then be used only after a thorough investigation of alternatives.

Although it is common for material drawn from a silo or inside storage bin to be delivered directly to a process machine hopper, it is equally common that the material will be subject to pre-processing treatment before delivery to the processing machine. In many cases, there can be several different steps through different pieces of auxiliary equipment before the resin is conditioned for processing. In designing a resin handling system, all of these actual or potential intermediate steps should be considered in the system design. In every case, a thorough early analysis will produce a system design that both functions better and costs less in the short and long term.

Piping Systems

Piping for dilute phase pneumatic conveying systems involve two major concerns, design and construction.

Design of a piping system requires careful consideration of factors that can doom a system to failure or marginally acceptable operation. Some basic rules that should be strictly adhered to:

1. All runs should be direct between material pick up and drop off with the least number of direction and elevation changes as possible.
2. A straight horizontal run of at least five to six feet should be present before every direction change (elbow). This run should be progressively longer for larger pipe sizes. A good rule of thumb is to allow a five-foot run for two-inch pipe and adding an additional 5 feet for every inch the pipe diameter increase. A five inch diameter conveying line would require 5 + 5 + 5 + 5 = 20 feet of horizontal run before each elbow.
3. Angled rises should not be used unless necessary.

Construction of piping system generally involves consideration of both the type and material to be used. Most pneumatic conveying tubing is made of aluminum because of aluminum's light weight and corrosion resistance. Galvanized carbon steel (EMT) is also used in smaller line sizes of 1-1/4 inch and 2 inch (note that these are inside diameters not outside diameters as with aluminum tubing). EMT is slightly less expensive installed than aluminum thin wall tubing. It is also heavier and more prone to corrosion, especially when used outdoors. Thin wall stainless steel tubing and schedules 10 and 40 aluminum pipes are used less frequently and at an obviously higher cost. A frequently used combination is aluminum thin wall tubing for low wear straight runs with thin wall stainless steel elbows for high wear bends. This combination is both durable and cost effective.

Tubing lengths and elbows are normally connected together by galvanized or stainless steel, gasketed, compression type three or four bolt couplings. These should always have a grounding strap included since the gasket is usually an insulator. Isolated sections of conveying tubing can build up a substantial and potentially dangerous static charge from the conveying process.

Most plastic pellets are in a dilute phase system are conveyed at pick up velocities of 4,000 - 4,500 feet per minute. This is because the drop out or saltation velocity of most plastic pellets is around 3,500 FPM. This is the point where the pellets are no longer conveyed by the air stream and either pile up at the bottom of a vertical rise or fall to the bottom of a horizontal run. When this occurs, the line frequently "plugs" and must be manually cleared before conveying can be resumed. On the other hand, when some plastic pellets such as polypropylene (PP) and low density polyethylene (LDPE) are conveyed at these velocities, the heat generated from the plastic pellets sliding along the length of the pipes and elbows creates long thin pieces of plastic. These are commonly known as streamers. Streamers can clog parts of the system, especially when they ball up to form a "bird's nest." Unfortunately, the nature of dilute phase conveying is such that conveying velocities increase with the distance conveyed due to the expansion of the compressed conveying air as its pressure drops while it moves to the terminal point in the run. At times, the velocity near the end of a run can be in excess of 7,000 FPM.

A considerable amount of research has been done to solve or minimize the problem of stringer formation. Consequently, three types of treated pipe and at least two variations of blind tee, pocketed elbows are presently available as solutions. The treated pipes have their internal surface roughened by sandblasting; directional shot peaning or spiral grooving. Performance tests have shown reductions of up to 70% of stringer formation with these treatments. Pocketed elbows create a sharp directional change unlike the gradual sweeping flow of a long radius elbow. The pocket forms an area for incoming pellets to impinge on pellets rather than the back wall of the elbow. Performance tests have shown reductions of over 90% of stringer formation in systems with these elbows. All of these products have significant costs associated with them. These costs are for both the materials themselves and the need to upsize the conveying equipment to offset the lower conveying efficiency experienced when they are used.

Controls

Bulk Unloading and Storage Systems and In-Plant Distribution Systems require control systems and wiring that, taken together, can constitute 50% of a systems capital investment. Degree of system control, integration and automation; type of operator interface and openness of the control system architecture will all play a part in determining the design and costs of a control system as will conformance to local and company electrical standards. At the least, all control systems should comply with National Electric Code and Fire Protection Safety standards.

Selection of control systems should take into consideration the ready availability of replacement parts; type of training required and available for maintaining the hardware and software and the availability of service technicians for trouble shooting the system.

System controls can be classified by degrees as manual, semi-automatic and fully automatic. In practice, most control systems are semi-automatic. Manual systems although inherently low cost, are not justifiable in terms of ongoing labor cost required. Fully automatic control systems, on the other hand, are not only prohibitively costly but also remove the ability for necessary operator decision making. A typical semiautomatic system for rail car unloading would function with the operator connecting the material vacuum line to a rail car compartment and the material pressure fill line to a manual switch station. Once connected properly, the operator would turn on the pull-push pump and initiate an unloading sequenced start-up, usually by push-button. The control system would then begin a sequenced start up of the system components. If a high level indicator in the silo signaled a full condition or a low vacuum sensor signaled an empty compartment the unit would initiate an automatic controlled shutdown sequence and sound or flash an alarm to allow the operator to reset the material source or destination. Additional automation might include electrically operated diverter valves to select which silo is to be filled; dirty pump inlet filter sensors and warning or shutdown sequences; graphics display interfaces to show operating parameters of system components and alphanumeric display interface with operating and fault messages.

Systems control integration can range from a stand-alone system logic where each component is controlled discretely to a fully integrated system where all components are controlled by a central system. Discrete controls generally range from simple electromechanical starters, relays and switches through proprietary, microprocessor based, single board controllers to fully programmable, PLC based panels. Integrated controls for pneumatic conveying systems are usually programmable logic controller (PLC) or personnel computer (PC) based systems. In addition to controlling the conveying equipment, these integrated systems frequently control all of the material pre-processing functions and equipment in the system. A PLC or PC based, fully integrated system that does this is usually the most economical control system from both capital and operational standpoints due to the elimination of redundant control components and a level of control that eliminates most unnecessary operator interface with the equipment.

Openness of systems architecture becomes a critical decision factor when specifying a system control. Ideally, all control hardware should be off the shelf, national brand components. Where software is necessary for systems operation, this should be included as part of the systems documentation. Generally, PLC based systems will provide the processor with the highest level of "openness.” Programs for PLC and PC based systems should be written with well known, high level manufacturer's or third party's programming software. They should be provided with adequate commenting to permit the processor's personnel to follow the program flow for trouble shooting or subsequent enhancements and changes.

GRAVIMETRIC METERING AND BLENDING

by Clifford J. Weinpel

Gravimetric metering and blending has become the accepted method for introducing two or more materials into the extrusion process. The transition from volumetric to gravimetric equipment began in the late 1960's. Since then, it has been well established that the advantages of gravimetric technology over volumetric are easily cost justified. Today, specifying volumetric metering and blending for a film or sheet extrusion line is a rare occurrence. There still remains a need to approach metering and blending as part of a decision making process. Where earlier the choice was to determine if volumetric or gravimetric equipment was appropriate for the task, now the decision process revolves around selecting the right type, configuration and features of a gravimetric system to specify for a process line.

It is necessary to understand that what is commonly referred to as a gravimetric blender is, in reality, a combination of two elements. The first is a gravimetric metering element that determines the proportions of different ingredients supplied to the extruder. The second is a blending or mixing element that determines the homogeneity of the mix of those ingredients. The types of gravimetric metering elements that are normally applicable to the film and sheet extrusion process are: gain in weight - batch, loss weight – target weight, loss weight – target rate and additive proportioning feed throat. The types of applicable blending elements normally associated with these types of metering technology are passive (static), active (dynamic) or none. All the types of metering and blending elements come in different styles based on the requirements of the application and the suppliers providing the equipment. However, differences in gravimetric metering technology generally drive the choices in blending. There are no hard and fast rules regarding the combination of metering and blending elements. Most suppliers provide standard metering and blending packages that integrate the two elements based on prevalent industry applications with custom packages or individual elements available for unconventional applications.

There are three basic configurations for gravimetric metering and blending systems: extruder throat mounted, mezzanine mounted and floor mounted. Variations exist of the basic configurations that yield several possible arrangements of the metering and blending elements.

Gravimetric metering and blending systems that include scrap regrind in the mix of ingredients to be processed require additional consideration. The scrap regrind is typically a combination of on-line recycle in the form of trims and bleeds and off-line recycle in the form of roll and loose scrap. Film or sheet regrind has a bulk density normally one-tenth to one-half that of the other ingredients being fed into the process. Therefore, the blending element of the system must accommodate a broad difference in material properties.

GRAVIMETRIC METERING AND BLENDING

SCALE BASICS

Regardless of type, gravimetric metering/proportioning equipment generally used in film or sheet extrusion shares certain common features and elements. All incorporate one or more weighing elements, all utilize material storage hoppers and all have feeders or feed control devices.

The most common weighing element used on today's gravimetric metering equipment is the strain gauge load cell. Significantly less common are load-sensing systems based on vibrating wires, linear voltage differential transformers (LVDT) or piezoelectric crystals. These alternative load-sensing technologies have advantages over load cells in different environments and applications. The vast majority of weighing applications in film and sheet extrusion, however, do not derive a major benefit from using any of these alternatives. Load cells are commercially available from a number of manufactures and are designed in a number of types, styles, accuracy classes and load capacities. Two of the most common types are the cantilever and "S" beam (Fig. 9). Depending on the style, a load cell can be used in tension, where the applied load is suspended from the cell or in compression, where the load is placed on top of the cell.

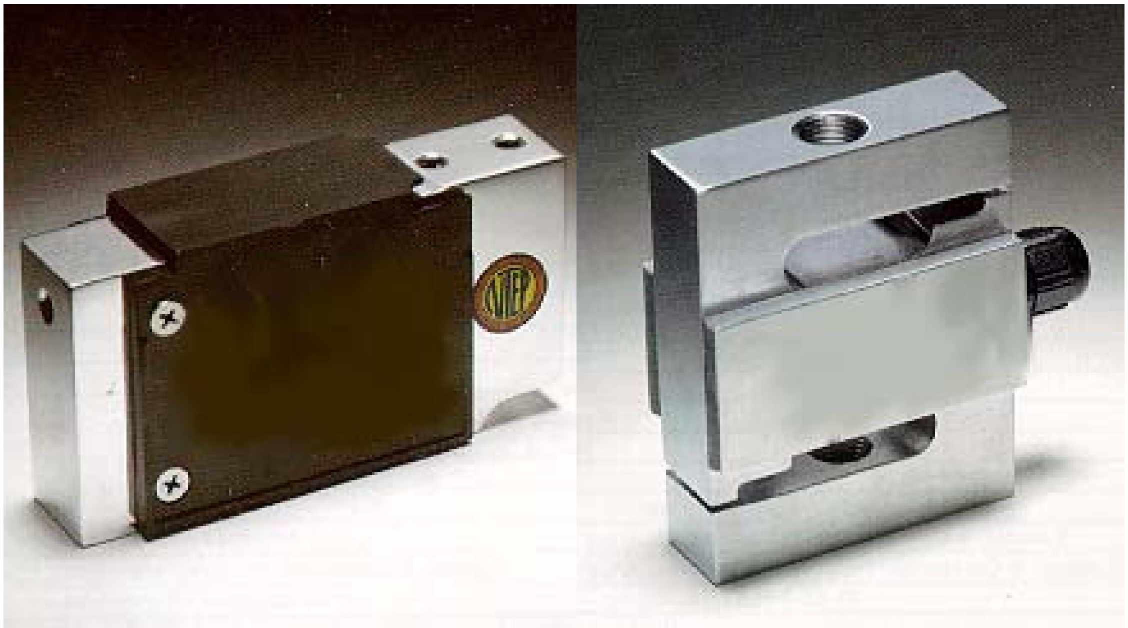

Figure 9. Typical Strain Gauge Load Cells – Shear beam load cell (right) is normally used with weight applied from above on one end and cell fastened to support from bottom at opposite end. An "S" beam load cell is normally used in tension with the cell fastened to support from the top and weight applied from the bottom, however, it can be used in compression with the support and load reversed.

The function of a load cell is the same weather used in tension or compression. As a load is applied to or removed from the cell, strain gauges bonded to the cell, which are "excited" by a regulated DC voltage applied to the cell, change resistance. Configured as a Whetstone bridge, the change in resistance of the strain gauges causes a change in the voltage measured across the output side of the cell. This output voltage varies proportionately with the applied load. Typically, the output voltage from a load cell ranges from zero at no load to thirty or forty-five millivolts at full load. The motion of the load cell itself between zero and maximum allowable load is only a few thousandths of an inch, well within the elastic limit of the cell design.

The load cell output, an analog voltage in the range of 0-45 mV is a low level voltage signal and as such, susceptible to external electronic "noise". To limit the effects of noise on the control system, this millivolt signal is either boosted to a higher analog range, typically 0-10 volts DC, converted to an analog milliamp signal, typically 4-20 mA, or digitized. This is done as close to the load cell as possible. If the signal remains in the analog domain during transmission, it is digitized later. During the conversion process from the analog to digital domain, the signal is resolved. Resolving the analog signal divides it into digital "bits". Each of these digital bits represents a portion of the applied load and is proportional to that load. An 8-bit A/D (analog to digital) converter is capable of resolving a signal into 2^8 =256 divisions. A 12-bit A/D converter provides 2^{12}=4,096 divisions of resolution. Likewise, a 16-bit A/D yields 2^{16}=65,536 divisions and a 20-bit A/D yields 2^{20}=1,048,576 divisions. It can be seen then that a 16-bit A/D converter provides 16 times the resolution of a 12-bit converter. As will be discussed in greater depth later in the presentation, this difference becomes important when considering the sensitivity and responsiveness of the gravimetric metering equipment.

METERING

There are numerous metering devices used to control the proportions of ingredients in a mix. In the plastics industry the most common devices in use today for pellet, flake, fluff and most free flowing powder are: gates and valves, vibratory pan feeders and auger feeders.

Slide Gates and Valves

Slide gates and valves are simple flow control devices. They are generally air or electrically operated and most often function in a full open/full closed mode. In some cases, they can be made to function in a staged or dithered mode to provide finer flow control. They are most often used as gravity flow devices, where the material passing through does not change direction out of a substantially vertical flow path. Because they rely substantially on the flowability of the material they are passing for uniform flow rates, they are used primarily as a low cost flow control device for gain in weight – batch type metering systems.

Vibratory Pan Feeders

Vibratory pan feeders are also simple flow control devices. They are electrically operated and most often are operated as variable flow rate devices where the amount of material being fed at any point in time is proportional to a variable input signal. In comparison to auger feeders, vibratory feeders are simpler devices with fewer moving parts. They tend to be more durable, cleanable, maintainable and cost effective than augers. They generally have a greater turndown ratio than auger feeders. However, they are significantly less linear in their input/output relationship at the lower and upper extremes of their operating range and they exhibit a hysteresis effect at their lower threshold. For this reason, their normal operating range should be centered and limited to a 10:1 turndown. These feeders are generally used on gain in weight – batch, loss weight – target weight and loss weight – target rate systems. Because additive proportioning – feed throat systems normally require the additive materials be fed into a head of gravity fed materials, vibratory feeders are rarely if ever used in this type of system.

Auger Feeders

Auger feeders are mechanically the most complicated of the three cited flow control devices. They are electrically operated and like vibratory pan feeders, are most often operated as variable flow rate devices. In comparison to vibratory feeders, auger feeders tend to be less sensitive to the effects of the materials being fed on controllability and linearity. They therefore require less complicated control algorithms and exhibit a quicker response profile. The turndown range of most auger feeders is in the 10:1 to 15:1 range, however this is usually extendable through a simple change of feed screw. Within the operating range of the weighing element, this capability allows a broader operating range for a metering station equipped with an auger feeder than for a similar station equipped with a vibratory pan feeder. Auger feeders are less susceptible to feed rate variations attributable to supply voltage fluctuations or material head pressure on the feeder. This can be particularly important in loss weight – target rate systems. On a station with a relatively low feed rate, a considerably long time can elapse before a corrective weight-loss signal can be supplied to a metering device, sometimes on the order of minutes. Under these circumstances, it is necessary for the feeder to be a stable volumetric device that can reliably hold a feed rate between corrective feedback signals. Moreover, the more linear the feeder input/output relationship is, the less corrective feedback will be required over time. Auger feeders are used in gain in weight – batch, loss weight – target weight, loss weight – target rate and almost exclusively in additive proportioning – feed throat metering systems.

BLENDING/MIXING

Blending technology relies on two parameters, intensity and duration. All blenders or mixers, weather passive (static) or active (dynamic), function by subjecting two or more ingredients to a level of agitation for a period of time. Passive mixing devices accomplish this by controlling the design of the mixing elements to determine intensity and the mixer column height to determine duration. Both parameters are essentially constants for a passive mixer and are not easily changed. Active mixing devices control intensity through mixing element design and the ability to vary speed. Active mixing duration is controlled by gating the mixer discharge to produce intermittent discharge or discharge flow control. Both parameters are variables for an active mixer and are easy to change. Passive mixing is essentially a two dimensional process while active mixing is three-dimensional. The advantages of active mixing over passive are controllability and versatility. The advantages of passive mixing over active are simplicity, cost, durability and maintainability.

Passive (Static) Mixers

Passive (static) mixers have been commonly used as either liquid or dry bulk blenders in the plastics industry for decades. When used to blend plastic resins they are usually configured as a cascading, baffled, gravity drop chutes for free falling materials and stream splitting mixers for plug flowing materials (Fig. 10). These mixers accept multiple ingredients, accurately proportioned by multiple feeders above, and through the action of their mixing baffles or elements, homogenize these ingredients somewhat. Generally, the mixing action is performed only in the directions perpendicular to the material flow direction. Therefore, variations in the “short term” proportionality of the ingredients being fed are not averaged through mechanical back blending. Passive mixers of these types are used under the design assumption that the materials being mixed require little if any mixing in the direction of material flow. This assumption works best if: 1.) The materials are accurately metered on a relatively short-term basis, 2.) Once mixed the materials are not subject to conditions that would cause de-mixing and 3.) The extrusion process provides adequate mixing to smooth out short-term proportionality variations. Both loss weight – target rate and additive proportioning – feed throat metering elements are easily configured to satisfy the first two conditions. In fact, additive proportioning – feed throat metering is often provided without a blending element before the extruder.

Active (Dynamic) Mixers

Active (dynamic) mixers (Fig. 10) have also been used for decades. Generally, gain in weight – batch systems always utilize active mixers because the batch method of metering is a sequential process that produces a very accurate proportion of ingredients that is stratified before mixing. This requires the intensity of an active mixer to produce an adequate blend. Loss weight – target weight systems also use active mixers. As with a target rate system, the metering process is simultaneous and proportional. However, one of the main advantages of a target weight system is the combination of highly accurate ingredient proportionality combined with a homogeneous blend. This combination is achieved through the batching action and the intensity of an active mixer. Centralized, floor mounted or mezzanine mounted gravimetric proportioning units, configured to provide ingredient blends of different constituents and proportions to multiple extruders frequently utilize active mixers above the throat of each extruder. This serves the dual purpose of assuring an adequate blending of ingredients after conveying to each extruder and providing an active surge hopper above each machine.

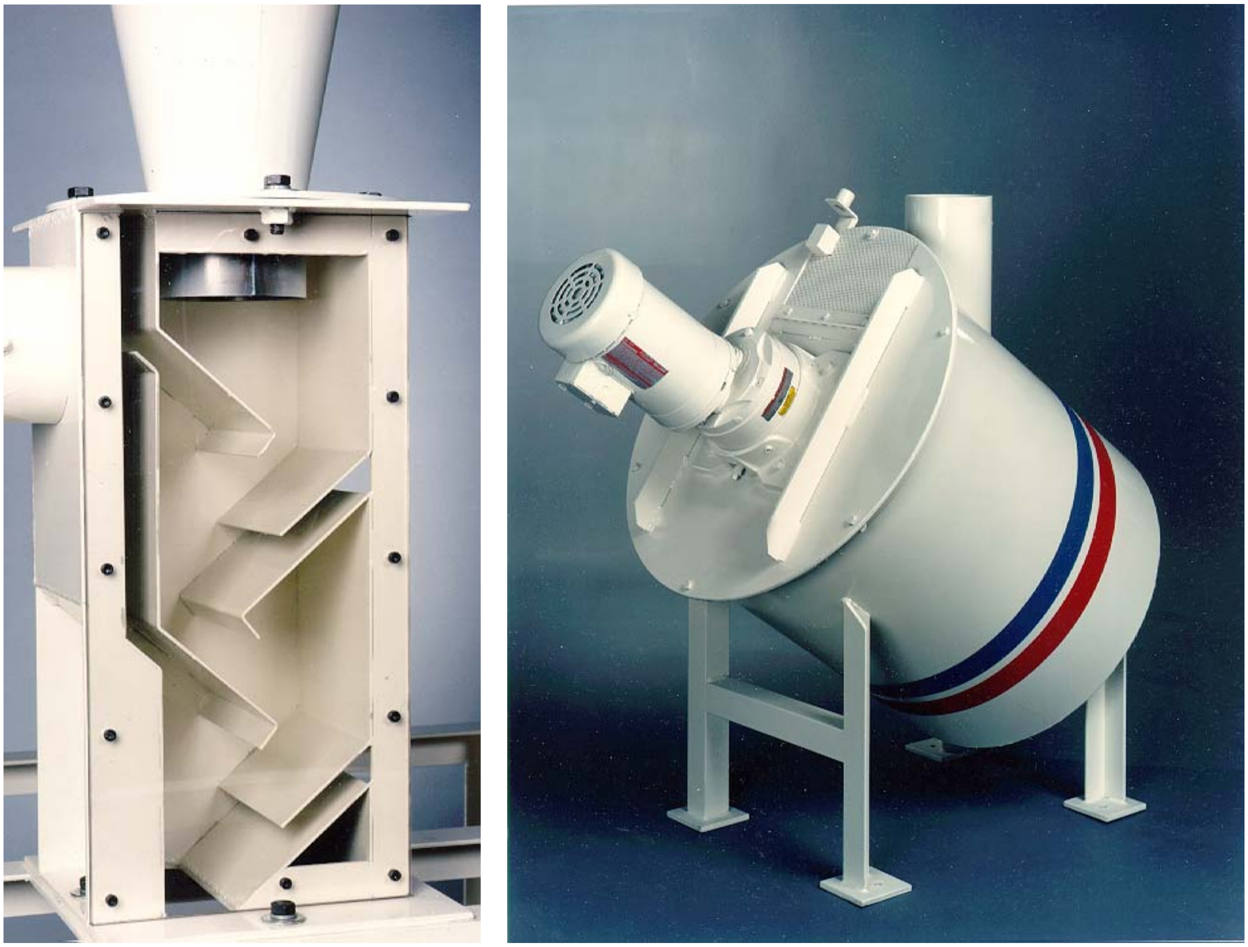

Figure 10. Typical Static (left) and Dynamic (right)Mixers

PACKAGED GRAVIMETRIC METERING AND BLENDING SYSTEMS

Packaged metering and blending units are provided by many suppliers for use in film and sheet extrusion. These packages consist of frequently combined metering and blending elements into single, integrated units. Except for unusual ingredient blends, custom configuration requirements or unique operating parameters, these packaged units generally represent the best selection choices for most processors.

Gain in weight – batch blender

Gain in weight batchers have been used in the plastics industry for over 25 years. Primarily used in the injection and blow molding branches of the industry, they have been frequently and successfully applied to film and sheet extrusion applications.

Most batch blenders (Fig. 11) have one weigh hopper and load cell fed by multiple metering devices. Each metering device feeds sequentially in turn into the weigh hopper. Normally, this is done using a bulk flow or high speed method. Either a self-tuning pre-act that adjusts the shut-off of the feeder or a self adjusting ramp-down to slow (dribble) speed is frequently used to ensure that the precise ingredient setpoint is reached. If one or more ingredients are to be less that 5% of the total batch by weight, a second weigh hopper is often used for these minor ingredients to maintain individual ingredient accuracy of ±0.5%. When a weighing cycle is complete, the weighed ingredients are released to an active mixer where they are homogeneously blended. The batch is then discharged to the process. Since sequential ingredient metering has a negative impact on total unit throughput, batch blenders are frequently programmed to perform the metering and mixing functions simultaneously. To maximize homogeneity and overall proportional accuracy of mixed ingredients, batch blenders are at times designed to accept multiple overlapping batches in the mixer. This provides a mechanical averaging technique where batch-to-batch inaccuracies are smoothed. Since a batching blender relies on a series of weighments to finalize a batch formulation, they are always at least one batch size away from a response to a change in formula. This mixed material in inventory can represent a processing problem if frequent changes in formulation are required to "tune-in" a product and the batch size is relatively large with respect to the processing rate.

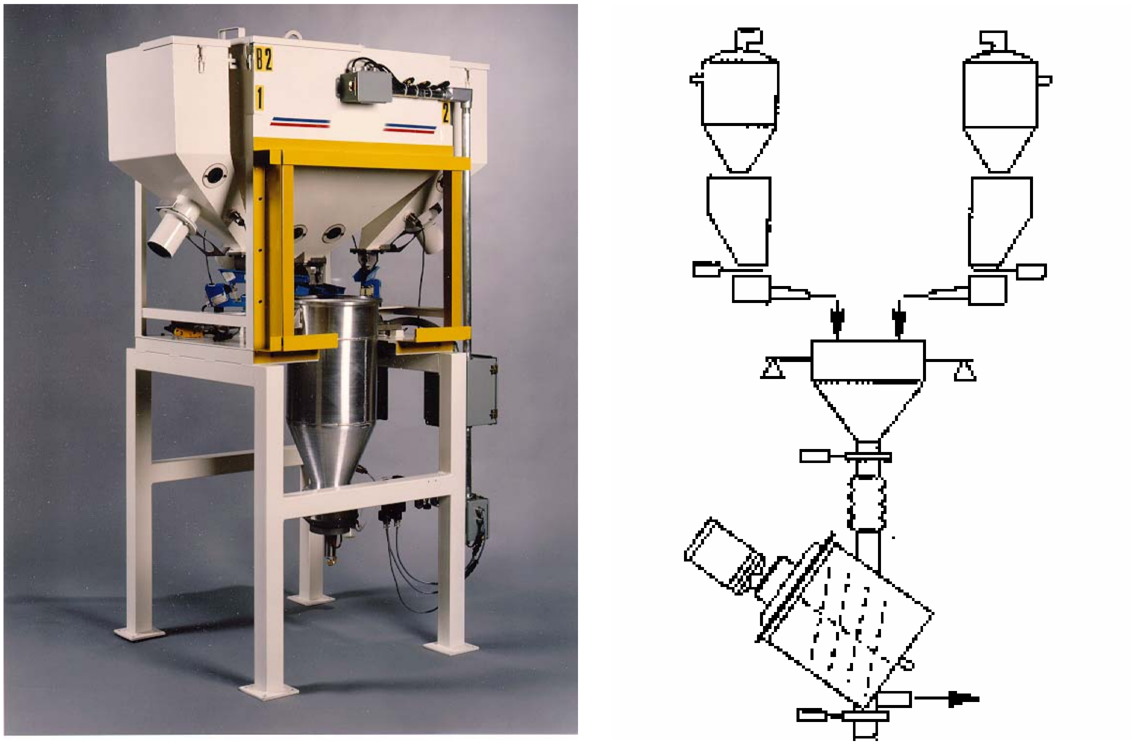

Figure 11. Typical Gain in Weight (Batch Blender) – Multiple feeders sequentially fill a weigh hopper to form a batch. The batch is blended in a downstream or integral mixer.

Loss in weight – target weight blenders

Loss in weight blenders, functioning in a target weight mode, have been used for film and sheet extrusion for over 25 years. Designed for a combination of high accuracy metering and homogenous ingredient blending, they provide these features at the higher processing rates typical of the extrusion process.

A typical target weight loss weight blender (Fig. 12) has each metering feeder mounted to an independent, load cell supported, weighing hopper. In some designs, the metering feeder is separated (de-coupled) from the weighing hopper to lessen the amount of "dead load" on the load cell. The purpose for this is to improve the resolution of the live load being weighed. This can be important when small amounts of a material are required in a formulation. However, de-coupling adds complexity to the system, is sensitive to poor material flow properties and can cause errors in the blend proportions if the principles of operation are not properly understood and followed. For these reasons, the majority of loss weight feeder stations supplied to the industry utilize a feeder coupled to the weigh hopper. Each weigh hopper measures the weight of material leaving it. The weighing system is programmed for simultaneous and proportional metering of each ingredient. Since each ingredient is weighed using an independent load cell, each cell can be sized and spanned to maximize the resolution of the A/D conversions. This yields very precise and accurate weighments. Although metering is done proportionally and simultaneously, this type of blender is programmed with a target, proportional weight for each ingredient with the proportional feed rates set and derived from the weigh proportions. The material that is fed out of the weigh hoppers is delivered to an active mixer. The feeding is paused after the target weights are achieved and the loss weight hoppers are refilled if necessary in preparation for the next gravimetric feed cycle. Since, unlike target rate blenders discussed next, refilling of the weigh hoppers is done while the feed cycle is paused, the feeders always run in gravimetric mode. All material fed is weighed. After the metered materials are mixed, the mixer discharges to the process and the next weigh cycle is started. Refilling of the weigh hoppers while the feed cycle is paused allows for self-loading vacuum weigh hoppers on this type of blender. This feature can be a significant advantage where adequate headroom is not available for separate weigh hoppers with vacuum receivers above.

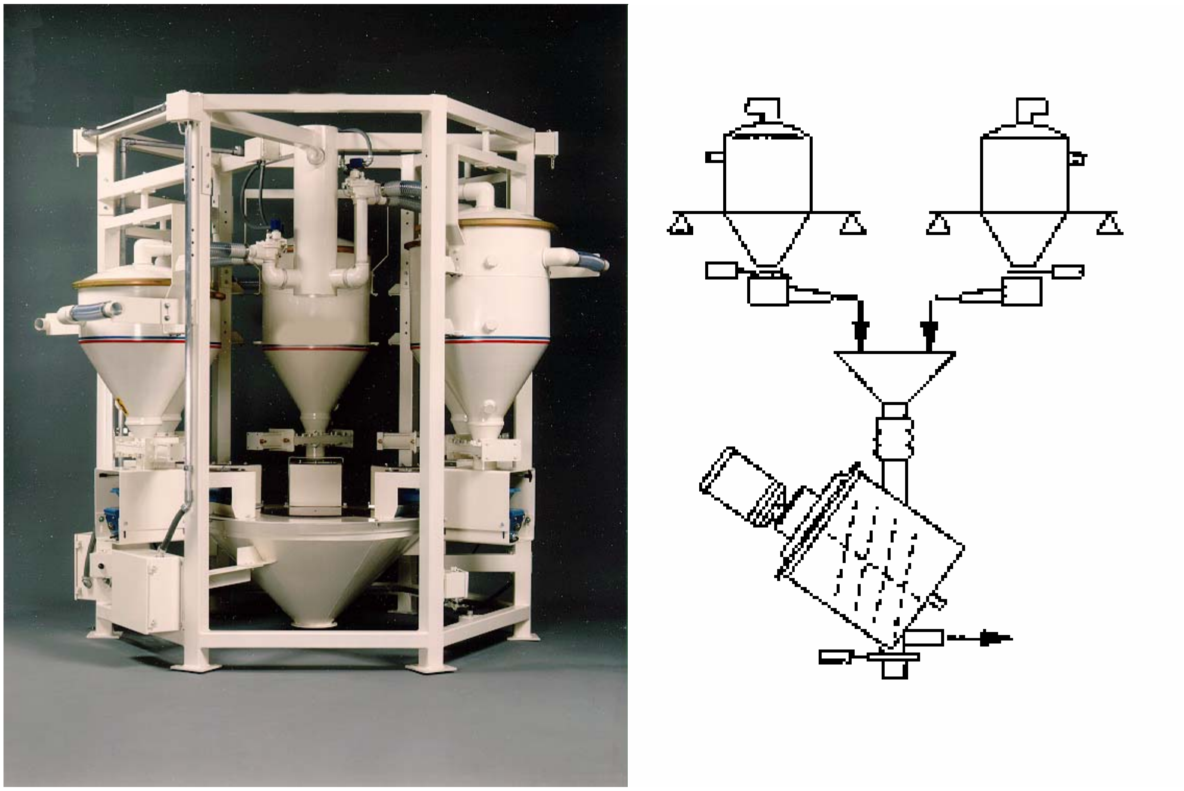

Figure 12. Typical Loss Weight – Target weight Blender – Multiple individually weight ingredients are fed simultaneously into a batch hopper or mixer to individual proportional weights. The batch is mixed and discharged to the downstream process.

Loss weight blenders – target rate

Loss in weight blenders, functioning in a target rate mode, have been used in film and sheet extrusion for over 20 years. This configuration of gravimetric blender is arguably the most prominent in film and sheet production and probably for all extrusion processes combined. The popularity of this configuration for extrusion focuses on a few features that add up to widespread acceptance. Target rate gravimetric blenders are a natural extension of their predecessors, volumetric blenders, which were the earlier industry standard. The similarities are both in form and function. Compact, easily positioned on or above the extruder throat, continuously rate proportioning with a passive or no mixer, gravimetric target rate blenders are a natural, self calibrating, self correcting replacement for the previous generation of volumetric equipment.

As with a target weight blender described previously, a typical target rate loss weight blender Fig. 13) has each metering feeder mounted to an independent, load cell supported, weighing hopper. Each weigh hopper measures the weight of material leaving it and the weighing system is programmed for simultaneous and proportional metering of each ingredient. A target weight blender is designed to feed continuously. The proportionality of the individual ingredients is determined by measuring the loss in weight for each ingredient over time (△W/△T). The target or setpoint for each ingredient is the rate, typically expressed as lbs./hr. (kg./hr.). Most often, the operator enters the desired ingredient proportions in percentages and the controller internally converts these to proportional flow rates. Since, in principle, proportionality in the direction of material flow is the target (rate) being controlled, passive mixing, at most, is all that is required in a target rate blender package. These principle assumptions lead to a number of physical and performance features common to target rate gravimetric blenders. Some are advantageous, others not.

A target rate blender with an integrated passive mixer or none at all can function with little mixed material in residence between it and the extruder. Typically, a short drop chute is located under the blender. The drop chute is generally equipped with level sensors, weight sensors or both. The level of material in the chute is sensed and the total feed rate of the blender is automatically adjusted to keep the amount of material in the chute at equilibrium. In this way, the feed rate of the blender is kept equal to the extrusion rate. The opposite control scheme, blending with integrated extrusion control, is also available as an option with most target rate gravimetric blenders. Instead of using the signal from the drop chute to proportionally adjust the output of the ingredient metering devices, the output of the blender is held at a fixed rate and the output of the extruder is adjusted to match the blender. This feature can be used to control overall product thickness in mono-layer extrusion and layer-to-layer ratio in multi-layer coextrusion.

Target rate gravimetric blenders achieve their highest levels of proportioning accuracy under relatively steady state operation. Proportionality in the short-term is an absolute necessity because, unless equipped with an active mixer, target rate blenders cannot mechanically average short-term variances. Likewise, mechanical feeding devices such as vibratory feeders and augers produce material surges and variations when they first start feeding and when they are at the extreme low end of their operating range. Feeder non-linearity can also be a source of short-term inaccuracy, especially when a feeder operates at the lower or upper end of its total design range. Another potential condition for short-term inaccuracy is a significant change in the selected target rate for an ingredient. This is especially true when the ingredient weigh feeder is operating at the low end of its span and the weight loss signal is accumulating slowly. In this case, there is a significant time lag between a target rate change and a weight feedback.

To minimize the negative effects on accuracy because of these conditions, the majority of target rate blenders are designed to run at a total throughput as close to that of the process rate as possible, at all times. To accomplish this, ingredient feeding is rarely paused and restarted. When an ingredient weigh hopper nearly exhausts its supply of material, the stations feeder is locked into its present feed rate. The weighing feedback loop is temporarily disabled and the scale hopper is refilled using the load cell signal to determine when the fill cycle is complete. From an accuracy standpoint, this refill cycle presents a problem. Without the load cell measuring the output from the weigh hopper, the metering process is out of gravimetric control. During this refill time, the proportioning system is essentially at a volumetric level of accuracy. It has been determined that if the total time a gravimetric metering system is out of gravimetric mode is 15% or less, the overall long-term accuracy is not significantly affected. For this reason, refill hoppers are normally situated above each weigh hopper. These are normally kept in a full status by the loading system. When a refill signal is generated by a weigh hopper, a valve is opened below the refill hopper and material is rapidly emptied into the weigh hopper, minimizing the time the metering equipment is in volumetric operation.

Target rate gravimetric blenders have their major advantages over the other gravimetric technologies in terms of their cleanability, mechanical simplicity and ability to be easily integrated into a gravimetric extrusion control system. They are particularly well suited for film and sheet extrusion lines that operate with frequent, short product runs and where relatively quick response to changes in ingredient proportions is required.

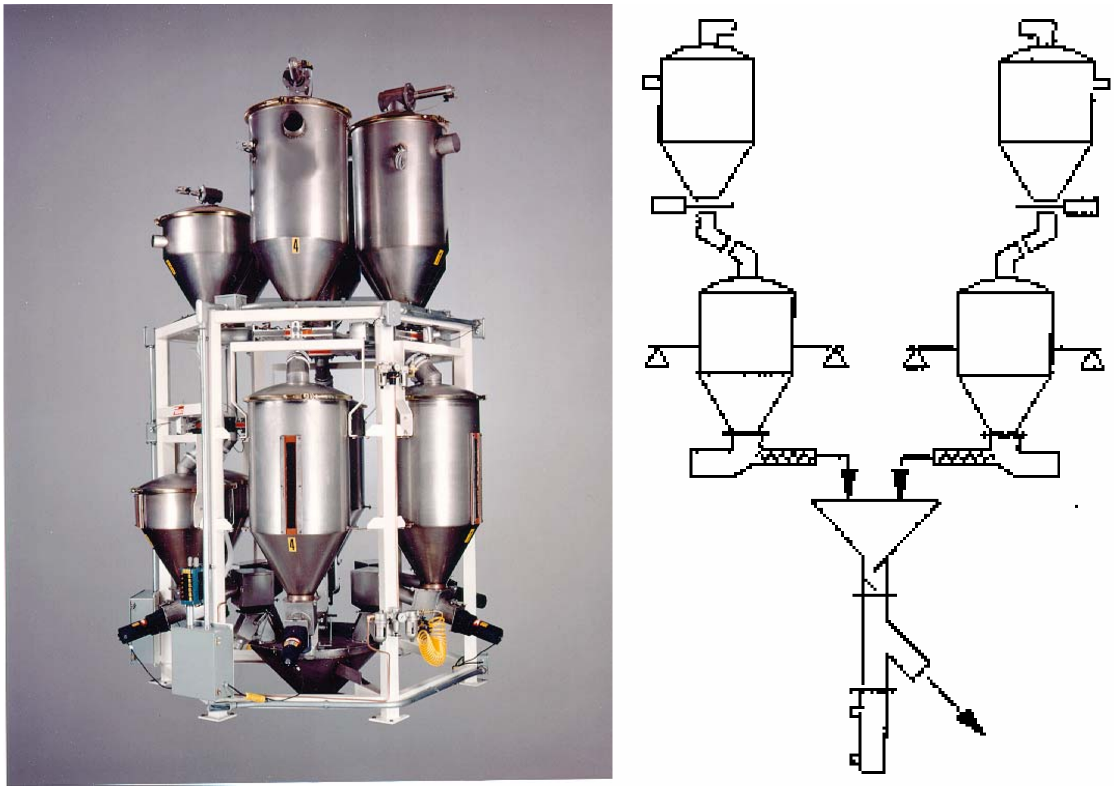

Figure 13. Typical Loss Weight – Target Rate Blender – Individually weighed ingredients are continuously fed at gravimetrically determined proportional rates directly to the downstream process. Static or occasionally continuous dynamic mixers are used if greater blend homogeneity is required. Feeders are usually locked into volumetric feed during refill of weigh hoppers.

Additive proportioning blenders – feed throat

Gravimetric feed throat blenders (Fig. 14) have been used in film and sheet extrusion for over 10 years. Similar in many ways to target weight blenders, they function under the design assumption that the extruder will act as the primary feeder of material in an extrusion/blending system. Under this assumption, a material feeder is not required for one of the ingredients to be fed. This ingredient is usually the major component of the ingredient formulation. Only a weighing hopper is necessary to determine the amount of that material being consumed. All other ingredients are metered proportionally by augers into the flow stream of the major ingredient as it enters the extruder throat. Because the extruder controls the flow of the major ingredient, the additional ingredients are injected into the plug flow of the major ingredient through an adapter located between the major weigh hopper and the extruder throat. The major weigh hopper is a mass flow device and is de-coupled from the extruder. Similarly, the additive weigh hoppers are generally de-coupled from their metering augers because the augers are required to feed into a plug flow stream of material. Without de-coupling, the forces acting on the additive augers from this process would prevent accurate weighing of the additive ingredients.

When a target formulation is entered into the control for a gravimetric feed throat blender, it assumes that the feed rate for the major ingredient will be the total extrusion rate less the combined total rate of the additive feeders. The proportionality of the ingredient mix is determined by both the extruder screw speed and the actual weight loss of each of the additive feeders. This in turn affects the actual amount of major material used. This nested loop control scheme can create conflicts between the major and additive ingredients. These conflicts can be especially pronounced when the sum of the additive ingredients is significant compared to the major ingredient. From a practical standpoint, an additive feed throat blender should control extruder screw speed to enhance proportioning control responsiveness. In fact, additive feed throat blenders are well suited for gravimetric extrusion and coextrusion control where all-pellet blends of one major and one or more minor ingredients are utilized. They can be especially advantageous where pellet materials of substantially different bulk densities or pellet sizes need to be introduced accurately into the extrusion process. Because the materials are combined proportionally, in a plug flow column, at the extruder throat, there is little chance of subsequent segregation.

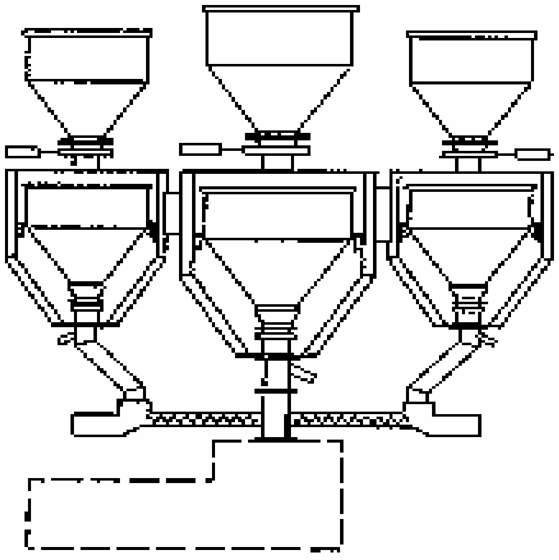

Figure 14. Typical Gravimetric Feed Throat Blender – The primary ingredient is gravity fed into the extruder throat with the additive proportioned by individual feeders

GRAVIMETRIC FILM AND SHEET RECYCLING

The subject of film and sheet scrap recycling is an extensive one for discussion and beyond the scope of this presentation. This section then is a brief overview intended to provide a general understanding of the potentials for gravimetric scrap recovery.

Film and sheet scrap generally are generated in two forms:

<u>On-line scrap</u> is generated during the extrusion process in the form of edge trims and bleeds. These trims are usually a constant portion of the film and sheet production process if trim-to-size is required or if edge product in a cast line is trimmed to ensure product uniformity in the cross extrusion direction. Trims and bleeds generally constitute 5-15% of an extrusion lines production. These are generated beginning soon after a product run begins and remain fairly constant throughout the run.

<u>Off-line scrap</u> is generated in the form of roll scrap and loose scrap. Roll scrap is most often generated at the start or end of a run when the product is not to specification. Occasionally it is generated when a problem develops with a line and the product is again out of specification. Loose scrap is frequently generated as peel backs at the end of a roll or as converted product that was discovered to be out of specification after downstream processing. Off-line scrap can be a more significant percentage of a products total volume. This is especially true in the case of a short run product that has experienced line problems during a run.

Today's business and environmental requirements rarely allow film and sheet scrap to be carted off to a landfill, as was the case in decades past. Sale of scrap to dealers remains an option, albeit a costly one. Repelletizing is an effective, but again costly method of dealing with scrap. The alternative is in-line scrap recovery.

In-line Sheet and film scrap recovery has been a standard, cost-effective procedure for dealing with scrap material for almost 50 years. Closed loop recovery of on-line scrap is a normal part of most film and sheet lines that generate trim scrap. The addition of off-line scrap to the process is handled almost as routinely. The advent of gravimetric blending brought with it a concurrent need to address scrap reprocessing. The answers to this need have resulted in solutions that are similar to those used with volumetric blending systems but that accommodate the change in blending technology.

Volumetric scrap recovery

When used in combination with gravimetric pellet blending equipment, film and sheet scrap can be recovered using volumetric methods equivalent to those used with earlier volumetric pellet blenders.

Extruder mounted dual channel feeders that normally introduce scrap material into a pellet stream can be used in essentially the same way. The gravimetric pellet blender simply replaces the volumetric predecessor (Fig. 15). Extruder mounted crammer feeders that normally feed a pellet/scrap mixture also can be used in essentially the same way. The premixed pellet/scrap blend again has the pellet portion of the blend metered gravimetrically with the scrap added as a volumetric component. Both of these methods of reintroducing scrap material are effective at eliminating the problems and expense of scrap disposal or Repelletizing. They are limited in that they assume that the scrap is not a critical component in the ingredient mix that requires careful monitoring to an accuracy level equivalent to the other ingredients in the blend. When gravimetric blending equipment is used in as part of a gravimetric extrusion control system, scrap recovery becomes more of a concern. At low levels of scrap (under 15-20 %), the scrap can be recovered and the estimated amount of scrap entering the extrusion process entered as a constant for the purpose of gravimetric extrusion control. This assumption produces satisfactory results if the scrap introduction rate is monitored and kept constant. Under a number of operating conditions, gravimetric scrap recovery is a superior solution. Typical examples are: multi-layer coextrusion where the multi-layered scrap introduced into one layer of a product can be critical to the formulation of that layer, or gravimetric extrusion control with higher than 20% or inconsistent levels of scrap recovery.

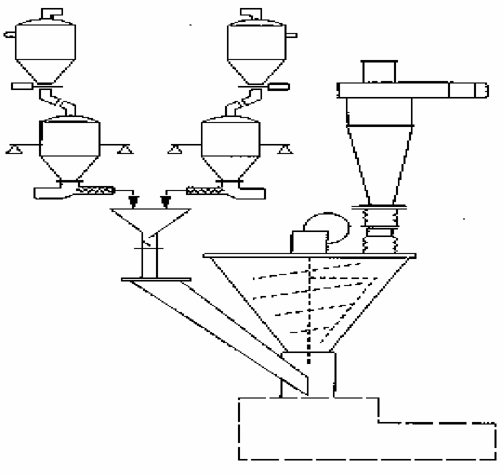

Figure 15. Typical Volumetric Film Scrap Recovery – The dual channel scrap re-feeder combines a Gravimetrically proportioned pellet blend with a volumetric film scrap recovery. A crammer feeder can be substituted for the dual channel refeeder for higher levels of film scrap.

Gravimetric scrap recovery

Gravimetric scrap recovery using an extruder mounted dual channel feeder (Fig.16) employs a scrap surge bin and a loss weight – target rate scrap metering station before the fluff feeder. The surge bin accumulates the on-line and off-line generated scrap and then supplies the downstream, loss weight scrap feeder when it signals for a refill. The scrap metering station gravimetrically adds the scrap material to the dual channel feeder where it is combined with the weigh blender's pellet mixture at the extruder throat. The first scrap storage bin can be equipped with load cells for a more precise control of the scrap recovery system. By monitoring the on-line scrap generation rate with the weighing system in the scrap surge bin and controlling the scrap re-feed with the loss weight feed bin the system gravimetrically controls scrap recovery.

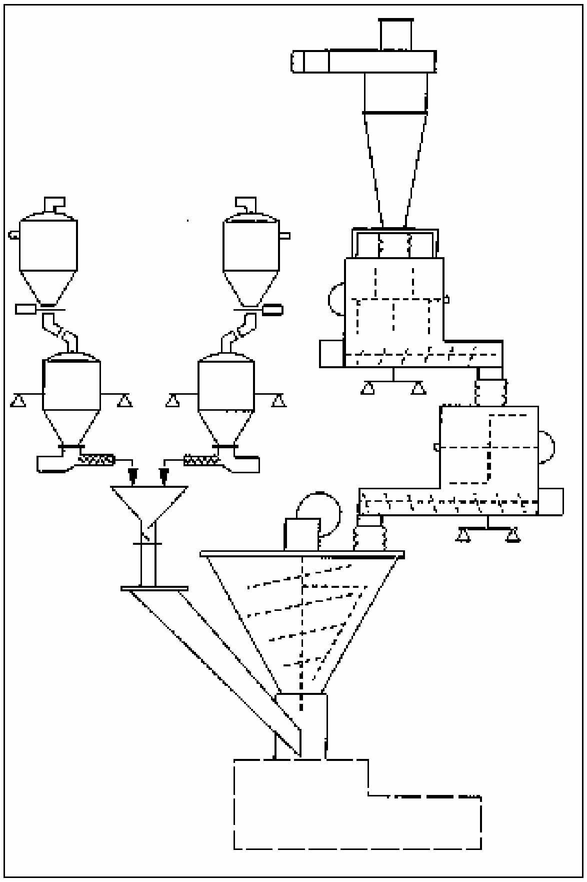

Figure 16. Typical Gravimetric Scrap Recovery with Dual Channel Scrap Re-feeder – Both the pellet blend and regrind are gravimetrically fed on a continuous basis.

Gravimetric scrap recovery using an extruder mounted crammer feeder (Fig. 17) for a premixed pellet/scrap blend also employs a scrap surge bin and a loss weight scrap metering station before the crammer feeder. The surge bin acts as the scrap accumulator and refill supply for the gravimetric scrap metering station. The scrap metering station gravimetrically adds the scrap material to the pellets being fed from the other blender stations and the mixture of pellets and scrap are introduced into the crammer feeder on the extruder throat.

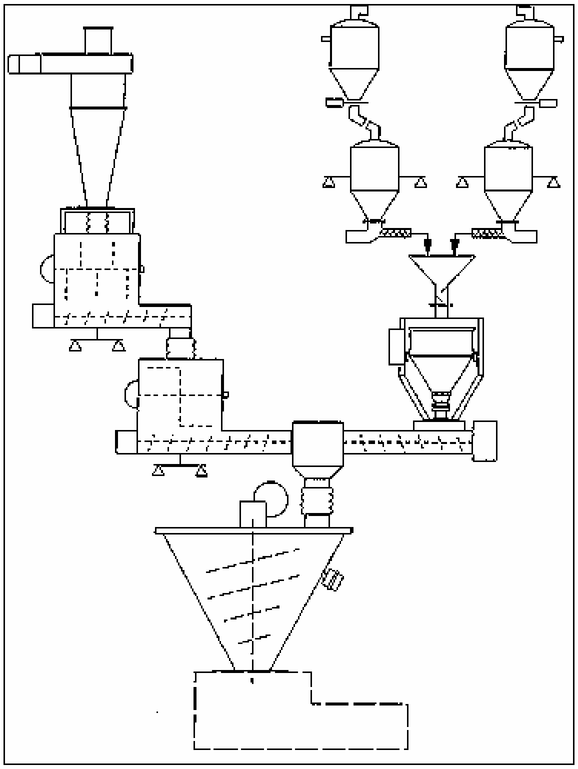

Figure 17. Gravimetric Scrap Recovery using a Crammer Feeder – The crammer feeder is substituted for the dual channel feeder when higher levels of scrap are to be reprocessed.

Scrap recovery, both volumetrically and gravimetrically, is commonly accomplished with gain in weight batch and both target weight and target rate loss in weight blending systems. Additive proportioning feed throat blenders are not normally applied in film or sheet extrusion applications with in-line scrap recovery.

GRAVIMETRIC EXTRUSION CONTROL

Gravimetric extrusion control is an added dimension to gravimetric metering and blending. In its conventional configuration, it is a simple extension of the metering and blending system to include analog inputs and outputs that provide the mechanism for automatic control of extrusion process parameters. By monitoring and controlling extruder throughputs by weight, process parameters such as weight per unit length and (in multi-layer systems) layer-to-layer ratios can be monitored and controlled.

The basic element of a Gravimetric Extrusion Control System (Fig. 18) is a Gravimetric Extrusion Control Hopper located at the throat of each extruder in the system. Similar to Gravimetric Blender Weigh hoppers, these devices utilize load cells to determine individual extruder outputs by weight and use this data to report and, when used in conjunction with other process I/O such as extruder screw speed and winder speed, to control extrusion parameters.

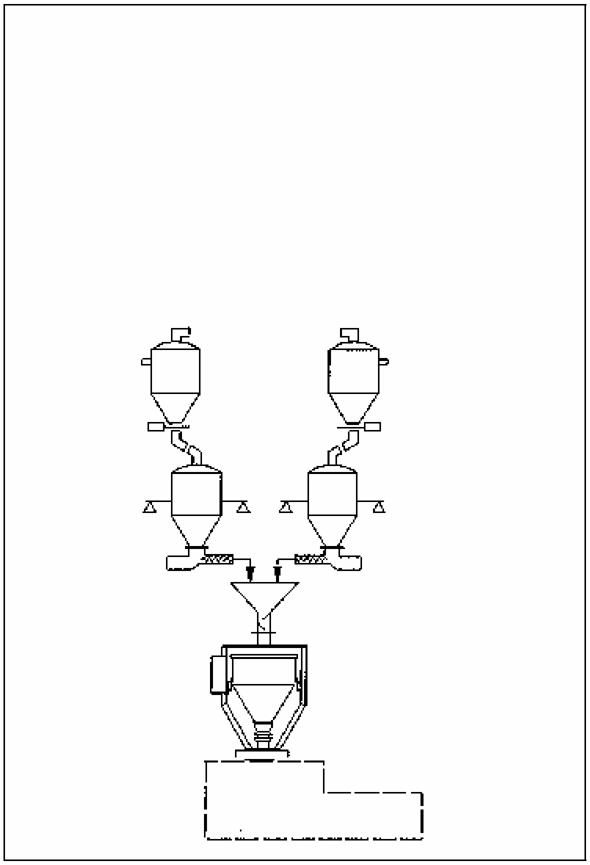

Figure 18. Typical System for Gravimetric Blending and Extrusion Control – The Gravimetric Extrusion Control Hopper which is mounted to the extruder throat can be integral to the blender or a stand alone device. Multi-extruder, multi-layer lines utilize a GECH hopper on each extruder to provide layer to layer ratio control.

The Gravimetric Extrusion Control Hopper (GECH) is employed in a number of ways, depending on the characteristics of the blending and extrusion systems in the process. A GECH hopper can be used as a continuous, zero reference value device. Applied in this way, the material usage data from the upstream gravimetric blending equipment is compared to the deviation from reference value, positive or negative, of the GECH hopper weight value. This provides the actual extrusion rate, by weight, on a real-time basis. In many cases, the GECH hopper is integrated into the gravimetric blender as a Weighing Drop Chute (WDC). In either configuration, the function is the same. Another system configuration, frequently used when the blending equipment in a system is located off the throat of the extruder, is with the GECH hopper equipped with a demand refill valve. Again similar to a gravimetric blender weigh hopper, the GECH monitors its loss in weight to the extruder over time. Periodically, when the material in the hopper falls to a predetermined level, the weight loss signal is ignored and the refill valve is opened until the GECH is full. This cycle is relatively short and so the operation of the system is effectively on a real-time basis.

In all probability, as many configurations exist for Gravimetric Extrusion Control as do for Gravimetric Metering and Blending. The important considerations for selecting and operating a gravimetric extrusion control system are essentially the same as for a gravimetric metering and blending system, notably, the fundamental concepts of accuracy, resolution and control.

ACCURACY AND RESOLUTION

The topic of accuracy has always been an area of controversy and at times misinformation and misinterpretation when associated with gravimetric blending. This discussion is an attempt to enlighten rather than obfuscate.

Accuracy and resolution are frequently confused when discussing weighing systems. The accuracy of a weighing element or station of a gravimetric blender is determined by the least accuracy of the scale components performing the weighing function. Before the advent of electronic scales, accuracy of a scale was a relatively simple thing to determine. Even today, the simpler the scale, the easier it is to determine its accuracy. As scales become more sophisticated, a determination of accuracy becomes more difficult. Determining the accuracy of a digital, electronic loss weight feeder with a de-coupled weigh bin is significantly more difficult then than of a mechanical balance scale.

Adding to the difficulty of determining accuracy is the difficulty in universally defining it. Load cell accuracy, for instance, is defined by a number of parameters and measured within a range of ambient and operational conditions (Fig. 1A). The way that these parameters are measured is carefully prescribed by at least two national agencies and a number of scale industry standards. If a scale is to be "sold over", such as the meat scale at the local market or the bag filling scales at the snack food manufacturer, they must be certified to NIST H-44 standards. These standards apply to the entire scale, not just the load cell.

Electronic scales have scale meters and mechanical elements that can easily introduce error far in excess of the allowable error in most commercially manufactured load cells of any accuracy class. Moreover, target rate and additive proportioning gravimetric blenders rely on the combined dynamic accuracy of a number of scales operating in unison, not the absolute weights of each ingredient fed to a mixture. The answer to all of this confusion is simplification. An accuracy statement for any weigh blender should not focus on the individual accuracy of one or more components in a system. A poor accuracy statement would be to say that a weigh blender uses load cells with an accuracy of ±0.01% of rated output. From the users standpoint, the system accuracy of the blender is the only accuracy of true importance. A good accuracy statement would be to say that a gain in weight – batch blender would produce accurate blends of ingredients to ±0.5% of setpoint for each ingredient, over the entire specified range of each ingredient feed rate and based on a specified range of ingredient densities and particle characteristics. This type of statement specifies the performance accuracy that the user can expect from the weighing system. More importantly, the statement is defined around measurable parameters that are important to the users product quality.

Accuracy statements for target rate and additive proportioning blenders are just slightly more difficult to formulate since "time" becomes an important parameter in the performance accuracy of these units. The addition of a meaningful time based parameter such as "…within 2 sigma based on a maximum of XX consecutive YY second samples" generally solves this problem.

Resolution of digital scaling equipment is another area of misinformation and misunderstanding in gravimetric metering and blending. As touched on earlier in this presentation, the resolution of a weighing system is a measure of the degree an analog signal can be divided up into digital bits. High resolution translates into a large number of fine divisions. For the most part, higher resolution is a good thing. On the other hand, lower resolution is not always bad. The parameters that determine the need or desirability for high resolution are the range and responsiveness necessary in a scale. Generally, target rate gravimetric blenders benefit from higher resolution more than batch weight and target weight blenders because of their time dependent proportionality requirements. From the point of practicality however, almost every present day gravimetric weighing system utilizes 16 or 20 bit A/D converters. A 12-bit converter used on a system today should be considered well below state-of-the-art and probably sub-standard. 20-bit A/D converters are usually overkill in a plastics production environment. Weigh systems manufactures however, are able to use the extra resolution of 20 bit converters to electronically enhance the stability and responsiveness of their scale equipment.

Beyond the scope of this discussion and more of a concern for weigh blender manufacturers than for users is the combination of load cell, dead load or tare weight, live load and A/D resolution on the weighing capabilities of a metering station. Generally, a weighing stations capacity should be sized for it's normal throughput range. Oversized holding capacities for low throughput stations or conversely, using high capacity stations for a low throughput usually results in insufficient resolution for accurate weighments.

Addendum "A"

Typical Single Pump Pull-Push Rail Car Unloader Specification

Parameters

Total Throughput: 40,000 lbs./hr.
Material: High density polyethylene (HDPE) with an average bulk density of 35 - 40 lbs./ft^3
Conveying Distance (Vacuum): 60-ft. horizontal
5-ft. vertical
(3) - 90 deg. elbows
10-ft. of flex hose

Conveying Distance (Pressure): 80-ft. horizontal
60 ft. vertical
(3) - 90 deg. elbows

Description:

1. One (1) Combination Vacuum/Pressure Power Unit Assembly complete with:

- Belt driven, positive displacement pump
- 40 HP TEFC motor (1.15 SF)
- Inlet and outlet silencers
- Pump protection cartridge filter with replaceable cartridge on vacuum side of pump
- Vacuum and pressure relief valves - adjustable
- Vacuum breaker valve, solenoid actuated, air operated
- Vacuum and pressure gauges, oil damped
- Check valve, pressure side
- All mounted on a carbon steel base with carbon steel drive guard and piped as a complete assembly

2. One (1) Transfer Station, pulse jet filter receiver type, designed to the following operating conditions:

Gas Volume: 680 ACFM
Gas Temperature: 274 deg. F. (max.)
Design Pressure: ± 17 in. Hg.
Air-to -Cloth Ratio: 7.5:1
Anticipated Loss: 3 - 5 in. W.G.

2.1. Filter Receiver:

- 5" O.D. tube material inlet & vacuum outlet
- Carbon steel construction
- Twelve (12) polyester filter bags, 0.5 micron with 90 ft^2 filter area
- NEMA 4 pulse jet solenoid enclosure
- Hinged access door
- Air header assembly with pressure gauge, FRL and all necessary piping
- Differential pressure gauge, 0 - 15 in. H_2O
- High level rotary switch tied to vacuum breaker valve through controls
- Manual maintenance slide gate at discharge, cast alum. body with stainless steel slide

Addendum "A"

Typical Single Pump Pull-Push Rail Car Unloader Specification

Page 2

2.2. Rotary Airlock:

- Cast iron housing
- Carbon steel rotor, welded eight vane construction
- Relieved blade tips and vane edge
- Outboard bearings
- 1 HP TEFC right angle gearhead motor
- Rotor at 25 RPM (Calculated at 1.6 ft^3/rev. displacement and 50 % pocket fill efficiency)
- Sprocket and chain drive with carbon steel drive guard
- Carbon steel pellet adapter
- Carbon steel discharge adapter with 5" O.D. tubing connection

3. One (1) Rail Car Unloader Control Panel complete with:

- NEMA 3R panel, free standing w/ 12" high leg kit
- Switch disconnect, through-the-door, w/lockout provision
- Main disconnect molded circuit breaker, 100 amps @ 480 VAC
- Individual branch circuit breakers for each motor starter
- All lights, switches and external mounted devices rated for outside service
- Emergency stop switch, mushroom head, push=stop, pull=reset
- Transformer, internally mounted to panel, 15 KVA rating
- Starters for power unit drive motor and transfer station rotary valve motor
- Programmable Logic Controller, Allen Bradley SLC-500 to control all railcar unloading/silo loading functions
- Panel graphics display to provide operator with equipment/silo designations and system overview for ease of operation

Addendum "B"

Typical Silo Specification

One (1) 12 ft. diameter by 56 ft. overall height welded steel silo, skirted type with a 60 degree cone hopper and a working capacity of 180,495 lbs. based on material bulk density of 35 lbs./cu. ft. Seismic Zone 1.

<u>Complete with:</u>

	1) Lifting rings
	2) 4-mil white epoxy interior - FDA approved
	3) 2-mil exterior copoxy primer - one (1) coat
*	4) Exterior finish coat of enamel over copoxy primer with a total of 3 mil minimum DFT. (white)
	5) Walk-in door (3' x 7') with louvers
	6) 12" diameter bottom discharge opening
	7) 20" diameter center dome with cover plate
	8) 2'6" ground clearance
	9) Foundation anchor bolts, anchor saddles and spacers
*	10) 4" OD nozzle on top offset (truck fill)
1	11) 20" manhole/vent combination
*	12) High level switch opening on deck
*	13) Low level switch opening in bin wall
	14) Deck perimeter guardrail
*	15) Outside ladder with safety cage and landing platform per OSHA
*	16) Crossover walkway with guard and toe board, span between tanks
*	17) 4" OD aluminum load line brackets
*	18) Flanged opening on deck for level transmitter, 5" ID with 8" OD flange with cover
1A	19) Stub nozzle on deck for Donaldson vent filter 6" OD
1C	20) 20" vacuum/pressure relief manhole Combination
*	21) 4" OD load line assembly
*	22) 12" aluminum slide gate
2	23) Level transmitter 50' max.
2A	24) Level transmitter 100' max.
2B	25) Control for level transmitter (1-22) silos
1A	26) Donaldson filter assembly
*	27) High level switch
*	28) Low level switch
*	29) Aluminum vacuum tray adapter with (4)- 3" OD outlets
*	30) NEMA 12 enclosure with high and low level indicating lights and common alarm for silos
1B	31) Flange on deck for self-cleaning bin vent filter
1B	31) Bin vent filter, automatic, self cleaning

NOTES:
* - Indicates optional items normally specified.
1 - Choice required of item 1, 1A or 1B. 1C is required with 1A or 1B.
2 - Choice required of items 2A or 2B, 2C is additional. Also available is Strain gauge silo inventory weighing system or Ultrasonic continuous level indicator system.

Addendum "C"

Typical Bulk Handling Survey

Customer________________________________ Contact____________________________________
Location________________________________ Phone_____________________________________

MATERIAL TO BE CONVEYED:

Generic name____________________________
Bulk density___________(Lbs./Ft.^{3})
Flow ability:____Free Flowing ____ Sluggish ____ Bridges Angle of repose______(degrees from horiz.)
Normal particle size:_____________Range_______ to _______
Special characteristics (i.e. explosive, toxic, cohesive)_______________________________________
Delivered by:_____ Rail _____Truck _____other (specify)_______________________________________

BULK UNLOADING:

Method:_____Pull-Push _____Vacuum _____Pressure Rate:_________________(Lbs./Hr.)
Distances:

- Pull-Push: Source to Transfer Station - Horiz.______(Ft.), Vert._____(Ft.) Ells_____(Qty.) Hose_____(Ft.)
  Transfer Station to Silo - Horiz.______(Ft.), Vert._____(Ft.) Ells_____(Qty.) Hose_____(Ft.)
- Vacuum or pressure: Source to Silo - Horiz.______(Ft.), Vert._____(Ft.) Ells_____(Qty.) Hose_____(Ft.)

Railcar Manifold distance:________(Ft.), Pickups_______(Qty.) Hose_____(Ft.)

SILO STORAGE:

Quantity_____ Capacity_____(Lbs.)
Construction: _____Bolted _____Welded _____Skirted _____Leg _____ Steel _____Aluminum _____FDA
Special Accessories (other than on standard silo accessories selector)______________________________
Limitations: Diameter_______(Ft.) Height_______(Ft.)

SILO UNLOADING:

Method:_____Vacuum _____Pressure Rate:_________________(Lbs./Hr.)
Distances:

- Surge Bin System: Silo to Surge Bin - Horiz.______(Ft.), Vert._____(Ft.) Ells_____(Qty.) Hose_____(Ft.)
- Direct To Destination System, Vacuum or Pressure: Destination points_____(Qty.) If number of destination points is more than one,for each destination point, list the following information on reverse.
  Horiz.______(Ft.), Vert._____(Ft.) Ells_____(Qty.) Hose_____(Ft.)

INSIDE SURGE BIN:

Quantity_____ Capacity_____(Lbs.)
Construction: _____Bolted _____Welded _____Skirted _____Leg _____ Steel _____Aluminum _____FDA
Special Accessories (other than on standard silo accessories selector)______________________________
Limitations: Square or Diameter_______(Ft.) Height_______(Ft.)

SURGE BIN UNLOADING:

Method:_____Vacuum _____Pressure Rate:_________________(Lbs./Hr.)
Distances:

- Direct To Destination System: Destination points_____(Qty.) If number of destination points is more than one,for each destination point, list the following information on reverse.
  Point number_____Horiz.______(Ft.), Vert._____(Ft.) Ells_____(Qty.) Hose_____(Ft.)
- To Pre-processing Equipment:..Destination points______(Qty.) Description__________________ If number of destination points is more than one, for each destination point, list the following information on reverse.
  Point number____ Description____________ Horiz.____(Ft.), Vert.____(Ft.) Ells____(Qty.) Hose____(Ft.)

Addendum "C"

Typical Bulk Handling Survey

Page 2

PRE PROCESSING AUXILIARY REQUIREMENT:

DRYING:

Material____ Required Drying Time_____(Hrs.)
Required Drying Temperature_____(° F) Processing Rate_____(Lbs./Hr.)
Material Source__________________________________ Material Destination____________________________

BLENDING:

Type:_____Volumetric _____Gravimetric Number of Units_____(Qty.) Accuracy_____(± %)

For each unit required, provide the following information on the reverse side.
Unit No._____ Total Throughput required_____(Lbs./Hr.) Mounting:___________(Floor, Mezzanine or Machine)
Unloading Blender to _____________(Destination) Horiz._____(Ft.) Vert._____(Ft.) Ells_____(Qty.)

List all ingredients for each blender with the following information.
No. Name Form (pellet, powder, flake, etc.) Bulk Density (Lbs./Ft^3) Ratio to Total(% min) to (% Max.)
Material Source Horiz._____(Ft.) Vert._____(Ft.) Ells_____(Qty.)

SCRAP HANDLING:

Scrap Ratio______(% of total line throughput) Speed_____(Ft./Min.)(Pieces/Min.)
Form (i.e. tabs, edge trims, bleeds, etc.) include necessary parameters such as thickness, width, etc.
____
Pick up Method (i.e. Venturi Blower, In-line Cutter, Conveyor, etc.)_______________________________________
Source____Destination___________________________________
Distance: Horiz._____(Ft.) Vert. _____(Ft.) Ells_____(Qty.)

GRINDING:

Number of Units_____ Required screen size_____(In.) Throughput_____(Lbs./Hr.)
Method of Feeding (list all)____
Unloading Grinder To:____________________________
Distance: Horiz._____(Ft.) Vert. _____(Ft.) Ells_____(Qty.)

CRAMMER FEEDERS & C-in-C REFEEDERS:

Process Machines (Provide information on all machines, use reverse if necessary): Type______________________
Feed Throat Size_____(In.) Total throughput_____(Lbs./Hr.) Scrap Ratio_____(% of Total)
Other Production Requirements____
____

TUBING AND FITTINGS:

Tubing: Aluminum_____ Galvanized Steel (EMT)_____ Stainless Steel 304_____ 316____
Elbows: Aluminum_____ Galvanized Steel (EMT)_____ Stainless Steel 304_____ 316____
Couplings: Gasketed, Bolted Compression_____ Vitaulic_____ Other_____________________________________
Special Considerations and Unusual Obstructions____

PLANT DESCRIPTION:

Existing_____ New Construction_____ Wall Construction___________ Ceiling Height______(Ft.)
Door Sizes (for access)______________ Voltage_______________

Addendum "C"

Typical Bulk Handling Survey

Page 3

CONTROLS:

Descrete or Integrated Plant Wide System______________________________
Complete Specification: Attached_____ Required_____
Particular Component Brands Required______________________________

Computer Based Supervisory Terminal Required_____ Supervisory Software Required______________________
Interface with Plant Control Net Required______ Type of Net______________________________

ENGINEERING AND CONTRACT INSTALLATION:

System Engineering by: ______________________________
Certified Archetectual Drawings by:______________________________
Permits by:______________________________
Approval Drawings Required Prior to:______________________________
Installation: Begins No Later Than______ Ends No Later Than______ Labor: Union_____Non-Union_____
Equipment Access, Silos, Etc.______________________________
Equipment Available to Installer:______________________________
Local Crane Contact:______________________________Phone:______________________________
Local Licensed Electrical Contractor (Optional)___________________Phone:______________________________
Plant layout: Included_____ Available_____ Required_____

ADDITIONAL INFORMATION:

Addendum "D"

Typical Indoor Surge Bin Specification

One (1) welded carbon steel surge bin, leg type with a 60 degree hopper bottom and a working capacity of 2,500 lbs. based on high density polyethylene (HDPE) pellet material with an average bulk density of 35 - 40 lbs./ft^3 complete with:

- Sight glass, minimum 4-in. dia.
- Drain tube, minimum 4-in. dia. with manual slide gate
- 60 degree hopper
- High level switch, proximity type, 32 mm threaded, Turck
- Low level switch, proximity type, 32 mm threaded, Turck
- Common alarm panel (Nema 12), including globe light, klaxon, indicating lights and alarm silence button
- 12" manual slide gate, aluminum construction, hand wheel operated
- Aluminum vacuum tray adapter (2) outlets, 2" OD
- Vacuum loader receiver mounting extension, cast aluminum with integral, panel-type replaceable filter
- High legs for gaylord discharge from drain