3

Fillers Transportation, Storage, and Processing

3.1 FILLER PACKAGING

Fillers are usually packaged in multi-wall paper sacks, pasted valve sacks, or intermediate bulk containers. Sacks are handled in palletised units usually containing 50 sacks of 25 kg each or more. The choice of packaging is made based on consideration of speed of handling, material protection, the flow characteristics of the material, storage volume conservation, suitability for palletising and stacking, purity of product, stability, image projection, cleanliness, environmental safety, and waste disposal.[1] Chronos Richardson has over 100 years of experience with particulate materials. The Company designs equipment for packaging a variety of materials including fillers. The selection of bags includes 20 different designs. The following design criteria must be evaluated and specified:

- Material: paper, polyethylene, polypropylene, polymer metal coated
- Form of material: film, foil, laminate, woven
- Number of plies: 1 to 4
- Material mechanical properties
- Material permeability
- Type of plies: the same material (e.g., 4 layer paper), different layers (e.g., paper with PE in-liner), coating (e.g., 3 layer paper with coating or PE aluminum coated)
- Design: open mouth, cross bottom, pillow type, pinch-bottom, bag with carrier, block bottom
- Valve: external, internal
- Filling level
- Marking and coding

The bag design is also important to the manufacturers of fillers who handle large amounts of material. Bag filling lines are optimized to process specific materials and types of packaging materials. Figure 3.1 shows a fully automatic bagging and palletising line for valve bags developed by Chronos Richardson for a carbon black manufacturer. The carbon black is filled into 25 kg bags at a rate of 700 bags per hour. One of the constraints of the design presented here was that a large amount of material had to be filled with a product at a high temperature. The development of an automatic line for carbon black is a very challenging task. Carbon black is a very difficult material to convey and it is extremely dusty. The material is charged to a receiving vessel having a special surface treatment. The material is fluidized in the vessel to improve its flow characteristics and to facilitate precise dosing. Automatically filled bags are closed and deposited on a belt conveyor which transfers the bags to a palletising unit.

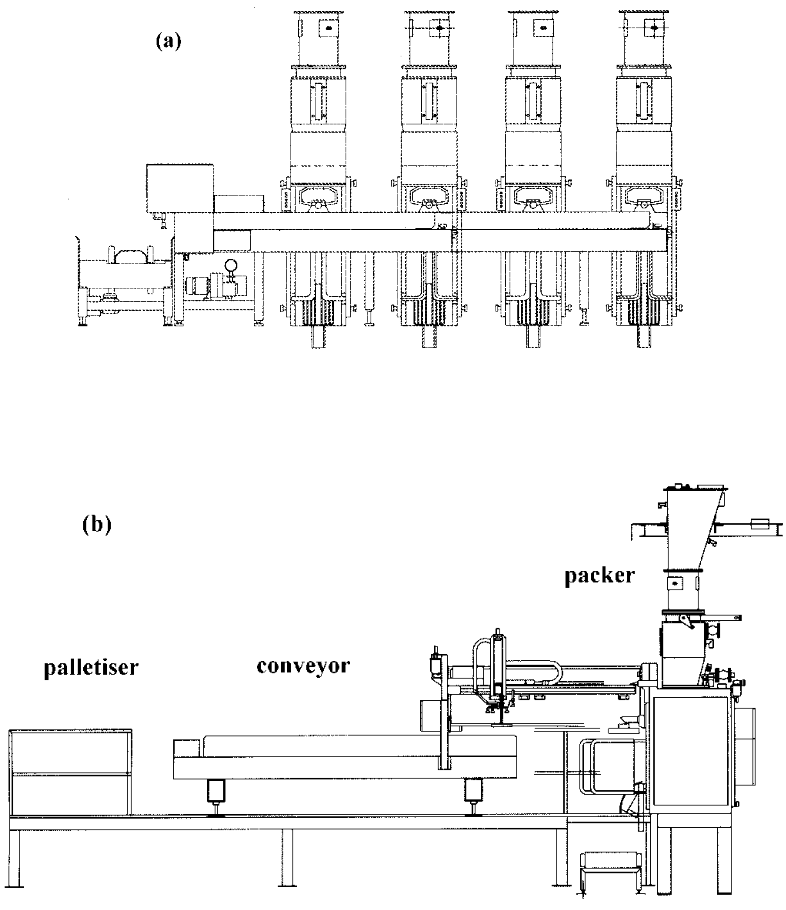

Figure 3.1. Schematic drawing of fully automatic bagging and palletizing line for carbon black packaging. *Courtesy of Chronos Richardson, Fairfield, New Jersey, USA.*

One cost efficient design is the form-fill-seal line which manufacturers flash cut bags, fills and seals them, places them on pallets, and wraps the pallets in plastic film.[1] The rate and quality of filling can be improved by the use of a spout carousel.

In the three spout carousel design, one bag is filled to the required weight, while the second bag is being air evacuated, and the third is being closed.

Air evacuation is a process to remove air from the material during filling. If air is not removed, the material will normally require a larger bag and bags will be unstable during handling, palletising, and storage. Chronos Richardson developed a unique technology which uses two porous filter lances which plunge into the filled bag and deaerate the product.[2] The filter lances must be designed by the manufacturer for a particular product based on experimental work. Twelve stable layers of bags filled with deaerated product can be put on a pallet.

Intermediate bulk containers vary in size and construction but usually contain about 1000 kg of product. These containers are made from coated or uncoated cloth and are equipped with a lifting collar at the top and a discharge valve at the bottom. Although in a chemical plant environment fillers packed in paper sacks is a common sight only 10% of fillers are transported in packages, the remainder is shipped in bulk. Only industries which are particularly strict about moisture content will prefer material packed in sacks. From the point of view of material handling and exposure to dust, fillers packed in sacks are least safe because they cause the highest emission of dust in the work environment.

3.2 EXTERNAL TRANSPORTATION

Fillers are delivered by traditional means of transportation, including rail cars, road vehicles, ships, and barges. Rail cars are used for delivery of bulk powder, paper sacks, and intermediate bulk containers. Rail cars usually have a capacity between 20 and 55 tons. The car for bulk delivery is compartmentalized; usually it has 3 sections, each equipped with release bottom doors, which are usually designed to control the discharge rate. Cars for bulk transportation should be lined with an appropriate coating to avoid contamination of fillers with rust.[1]

Road vehicles are mainly used for delivery of fillers in packed units, but transportation in bulk is also growing. Road tankers for bulk powder transportation can handle up to 50 tons. They are loaded through hatches in the tank roof, and emptied through a pipe (normally 100 mm in diameter) by self-discharging pneumatic conveying equipment which typically can discharge 10 m^3 of material per minute. Filler slurries are transported in stainless steel tanks which are also filled from the top, and discharged by positive displacement pumps able to discharge 20 tons in 10 min. The viscosity of slurry depends on the temperature; therefore, tankers used for cold temperature transportation should be insulated.

Transportation of bulk material by ships and barges is more complex because of the need for special equipment for loading and unloading. Loading is usually done by means of fixed or mobile conveyors. With proper equipment and organization, a loading capacity of 1000 tons/hr is realistic. Discharging of fillers is done by means of a variety of cranes and grabs. One crane and grab can usually have a rate of 75-100 tons/h; in larger ports, discharge rates of 300 tons/h are achievable.[3]

3.3 FILLER RECEIVING

Fillers can be delivered in bulk by rail or truck. Figure 3.2 shows a vacuum-pressure rail unload system designed by Premier Pneumatics, Inc. The elements of the system are explained on the drawing. Several systems are offered.[4] The dual blower, vacuum pressure system has the highest output at 45,000 kg/h. The system is equipped with PLC controls which include a destination selector and automatic shutdown. A smaller system with a 22,000 kg/h output can be operated by one person. It has a built-in hydraulic system which simplifies the attachment to rail car outlets and variable speed drives which allow operators to control the material feed rate. The company produces all of the required accessories such as Aerolock rotary valve meters with many choices of rotors, diverter valves, piping, couplings, adapters, gates, separators and receivers, and blowers. In fact, every component required for the design and assembly of these systems is offered.

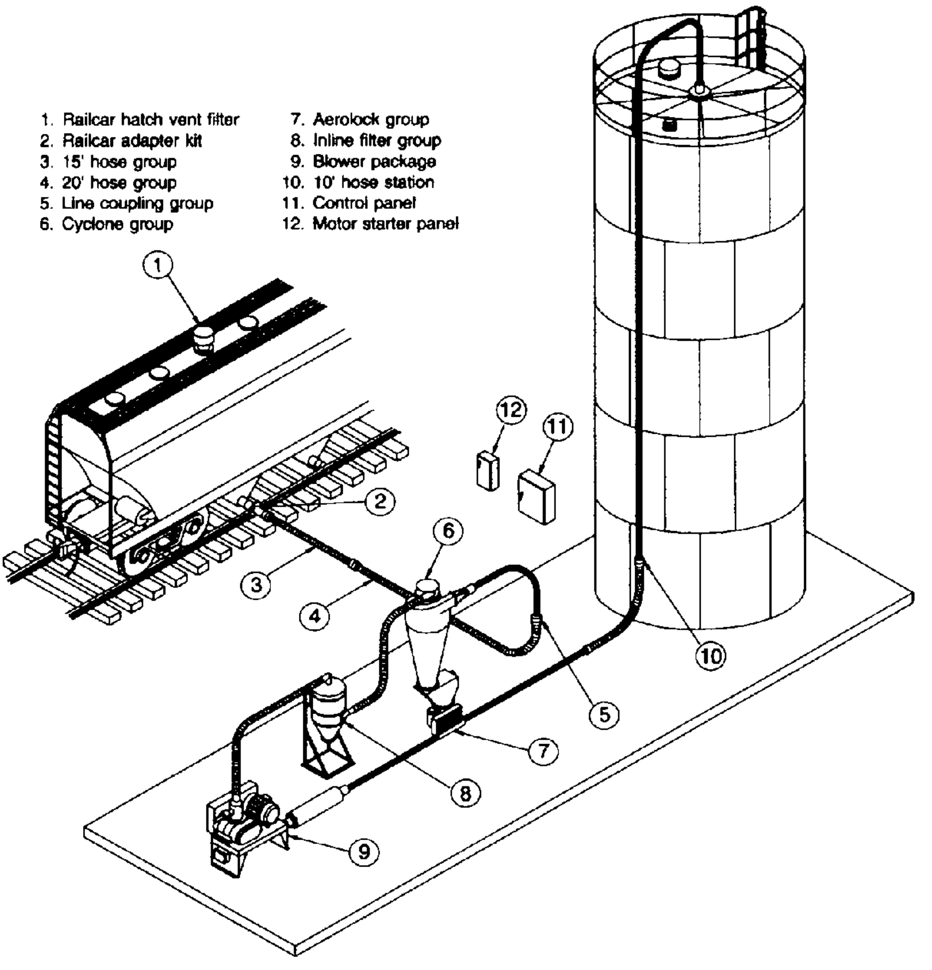

Figure 3.2. Vacuum-pressure unload system. *Courtesy of Premier Pneumatics, Inc., Salina, KS, USA.*

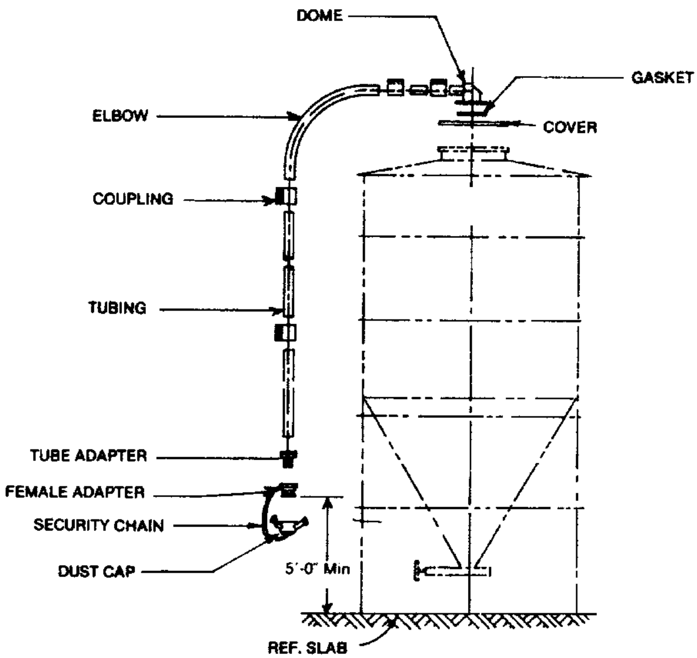

Figure 3.3. Load line assembly. *Courtesy of Premier Pneumatics, Inc., Salina, KS, USA.*

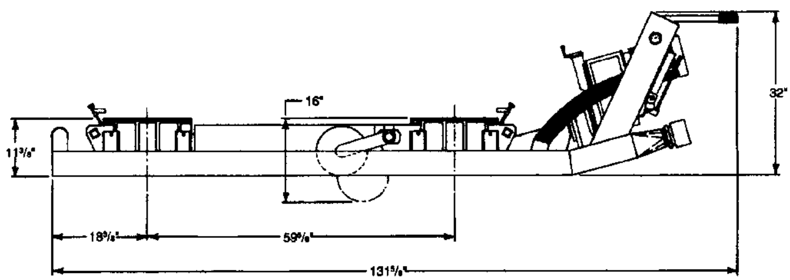

Figure 3.4. Manual railcar unloader. *Courtesy of Premier Pneumatics, Inc., Salina, KS, USA*.

Figure 3.3 shows various elements required to assemble a load line to a silo. The railcar can also be unloaded by a simpler, manual device (Figure 3.4). This unit can be used for Airslide railcars. The frame serves as a conveying airflow line. It should be noted that an explosion proof design is required for filler unloading.

The truck unloading installations have a selector switch for seven destinations, and an alarm to notify the operator when a storage tank is full. It is equipped with a blower and self-cleaning vent which provide a dust-free exhaust. The bag unloading stations are discussed below as part of in-plant operations.

3.4 STORAGE

Storage of fillers is a complex issue, and we will not attempt to discuss all its facets. Fillers are stored in portal frame buildings, general purpose warehouses, storage barges, bunkers, large hoppers, and silos. The choice depends on a large number of circumstances, but mostly on the material properties and the rate of use. Silo storage is very convenient and has these advantages:

- The storage capacity of a silo is several times greater than flat surface storage (floor storage)
- Transportation and packaging costs are reduced
- Equipment cost per unit volume stored is low
- Automatic handling and control is possible
- Controlled conditions of storage (temperature, moisture, etc.) are easily attained
- Quality of stored product is uniform
- The automatic process saves labor costs.

The diameter of a silo is usually 2.5 m or more. They are usually cylindrical with a conical bottom which has a 60° incline to facilitate discharge. There are two types of silos (hoppers): core flow and mass flow. They differ in principle because of the proportion between diameter and height in relation to the rate at which material is disposed. If a silo has a larger ratio of diameter/height and material is disposed in relatively small amounts compared with storage capacity, then material flows in the center (core silos). Mixing of material is minimal. Cohesive material may stop flowing for no reason. The rate of flow is variable and the bulk density of the filler will also vary. The material is not very stable in such a storage vessel and can be suddenly fluidized, leading to a rapid increase in discharge rate which might be hazardous. When the ratio of diameter/height is low (very tall), this becomes a mass flow silo) and the above disadvantages are avoided. Mass flow silos have some disadvantages such as the requirement of a tall building (if the silo must be indoors), high pressure on the side walls (stronger materials needed) and the abrasive action of filler on walls (faster wear). A decision on silo dimensions should be based on the flowability of filler.

The surface coating of the silo also plays an essential role. The exterior coatings are designed for UV stability, corrosion protection, high gloss and color retention. The interior coatings are even more crucial. Coatings must protect against corrosion, be abrasion resistant, and have chemical and thermal resistance. Compatibility with the material being stored contributes to proper discharge.

Many silos are fitted with a pressure relief disc in the roof which guards against silo damage during filling. Since most fillers have cohesive properties, discharging is aided by air pads or fluidized beds. Some materials gain in cohesion if left undisturbed. Figure 3.5 shows an example of a fluidized bed outlet manufactured by Premier Pneumatics, Inc. By introducing low pressure air into the stored material, the discharge process becomes less restricted and more uniform.

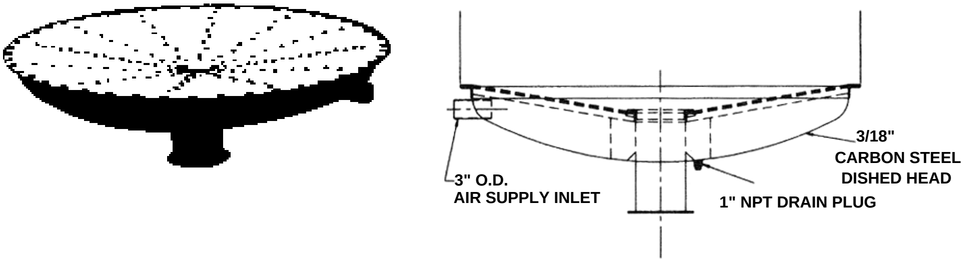

Figure 3.5. Fluidized bed activator. *Courtesy of Premier Pneumatics, Inc., Salina, KS, USA*

Fillers in the form of an aqueous slurry are stored in concrete or steel tanks. Care must be taken that the slurry temperature does not drop below 10°C. Handling problems develop when the slurry temperature is below 5°C. Overheating (above 35°C) should also be prevented. Materials packed in unitary packages should be stored in conditions specified by the producer. Bags are usually stored in a palletised form, whereas intermediate bulk containers are stacked three high, possibly on pallets or suspended on special metal pallets by means of loops.

A silo is also frequently equipped with a pneumatic conveying system, consisting of a blower, a rotary valve, conveying pipework, and an air/product separator at the discharge point. Some elements of the pipework are given in Figure 3.3. The discharge systems are discussed below. Suction systems can deliver material over a 600 m distance, low-pressure systems over a 1600 m distance, and high-pressure systems 3000 m and more. Conveying pipes have a diameter from 20 to 400 mm and a mass flow rate of up to 400 t/h is typical. A pneumatic conveyor requires more power for operation than a mechanical conveyor. Slurries can be transported by hydraulic conveyors. Conveying distances may be up to 400 km. Pipe diameters are from 60 to 300 mm.

Some silos may be equipped with flow measuring equipment. K-Tron Soder developed a system which is installed directly on the silo (Figure 3.6). This system is suitable only for free flowing material. In most cases the metering of the filler is conducted outside the silo and such solutions are discussed below. There is one exception - the use of a load cell system. K-Tron developed a vibrating wire Smart Force Transducer II which has exceptional performance compared to other sensors.[5] It is a digital sensor designed for process weighing with multiple data registers for data acquisition and advanced digital filtering for highly effective suppression of in-plant vibration. This design overcomes a frequent problem related to vibration in industrial environment which is compensated for by filters and does not affect measurement. There is excellent measurement resolution (1:1,000,000), no need for recalibration, error free data transmission, and data can be sent up to 500 m away. This transducer is also a part of various feeding systems discussed below.

3.5 IN-PLANT CONVEYING

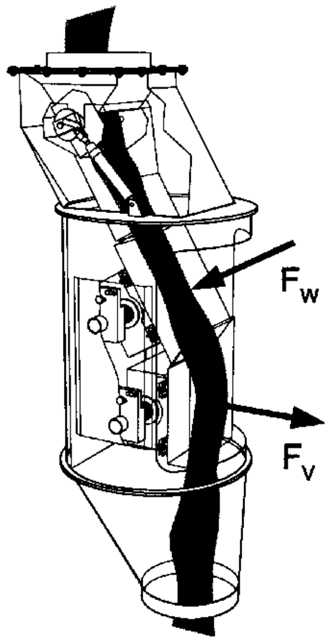

Figure 3.6. Smart flow meter bypass. Courtesy of K-Tron America, Pitman, NJ, USA.

When material is stored in a silo, an in-plant conveying system is required to transfer the material from the storage location to the point of use. The main components of such a system include a blower, piping, valve(s), receiver(s), filter(s), and control units.

Blowers are similar in construction to the units used in filler unloading from transporting units but usually reduced in size and capacity. Typical capacities range from 300 to 2000 kg/h. The choice of the right blower is critical for the operation of pneumatic conveying systems. Blowers, according to Premier Pneumatics, Inc. are designed to operate at 75-80% of rated capacity. Premier Pneumatics, Inc. produces three types of blowers: pressure, vacuum, and vacuum/pressure. Mini-Vac™ is the name of a modular system designed by Hapman. The system is suitable for applications where space is limited and high output is required.

The system vents through cartridge filters which are easy to replace. This system is used with multiple inlets and receiving points, for container unloading units, and for loading to containers. The schematic drawing shows the system components (Figure 3.7 The choice of a blower depends on the material characteristics and required output.

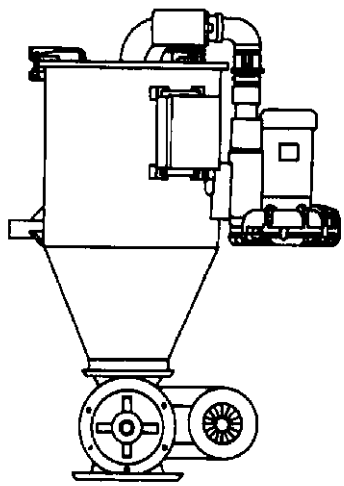

Figure 3.7. Mini-Vac compact blower with rotary valve. *Courtesy of Hapman, Kalamazoo, MI, USA.*

Figure 3.3 shows some elements of piping. The essential elements are pipe diameter, couplings, sight tubes, line branches (tees, wyes), and elbows. Some systems such as conveying systems for carbon black may contain aerators to prevent line plugging. Lines are usually 1.5 to 8" in diameter and are made out of aluminum, steel, or stainless steel. The designer should keep the number of branches, valves, and elbows to a minimum. Each causes obstruction to flow and potential problems in operation.

Several types of valves are used. The tunnel diverter valves allow the use of multiple supply or receiving lines. The A valve diverts the material stream to one of two destinations. The aeropass valve separates air from the material. The slide gate valve opens or closes to control flow. These valves can be either manual or automatic.[6]

Separators and receivers separate material from the conveying air before the point of use. They are either filters or cyclones. Figure 3.8 shows a schematic diagram of part of the line, the filter, receiver, and vacuum blower.

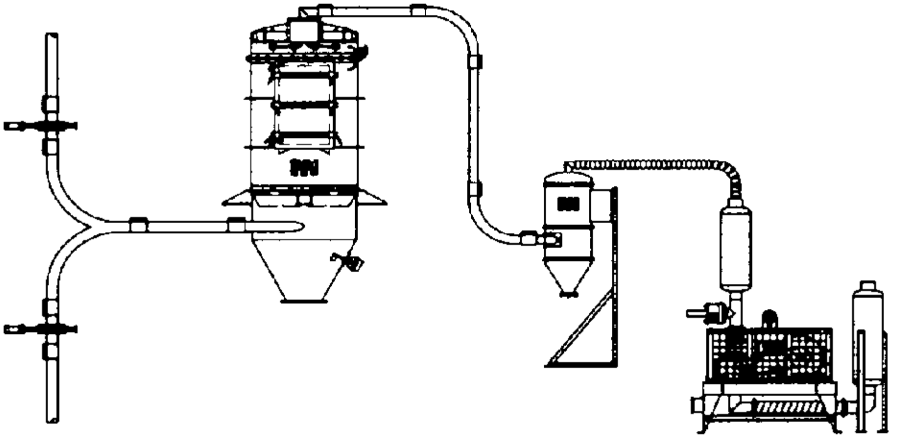

Figure 3.8. Elements of pneumatic conveying system. *Courtesy of Premier Pneumatics, Inc., Salina, KS, USA.*

Filters are used in conjunction with receiving units and blowers. In applications, where powder dusting is a problem, additional filtering systems are also installed. The whole system is operated from a central controller usually equipped with an alphanumeric backlit LCD display. Various levels of control and automatic operation are available.

Spiroflow-Orthos Systems, Inc. developed several mechanical and aero-mechanical conveying systems which may add to the flexibility of in-plant operations and eliminate unnecessary manual operations and dust. Figure 3.9 shows an aero-mechanical conveyor which can work in vertical, angled, and horizontal arrangement. The wire rope assembly with polyurethane discs moves at a high speed transporting the material to its destination. The rate of materials delivery depends on the conveyor size. For example, the 75 mm model can deliver 300 l/min and the 100 mm model 600 l/min. Materials from fine powders to granular particles can be moved by this design. Figure 3.9 shows some typical applications of this conveying system.

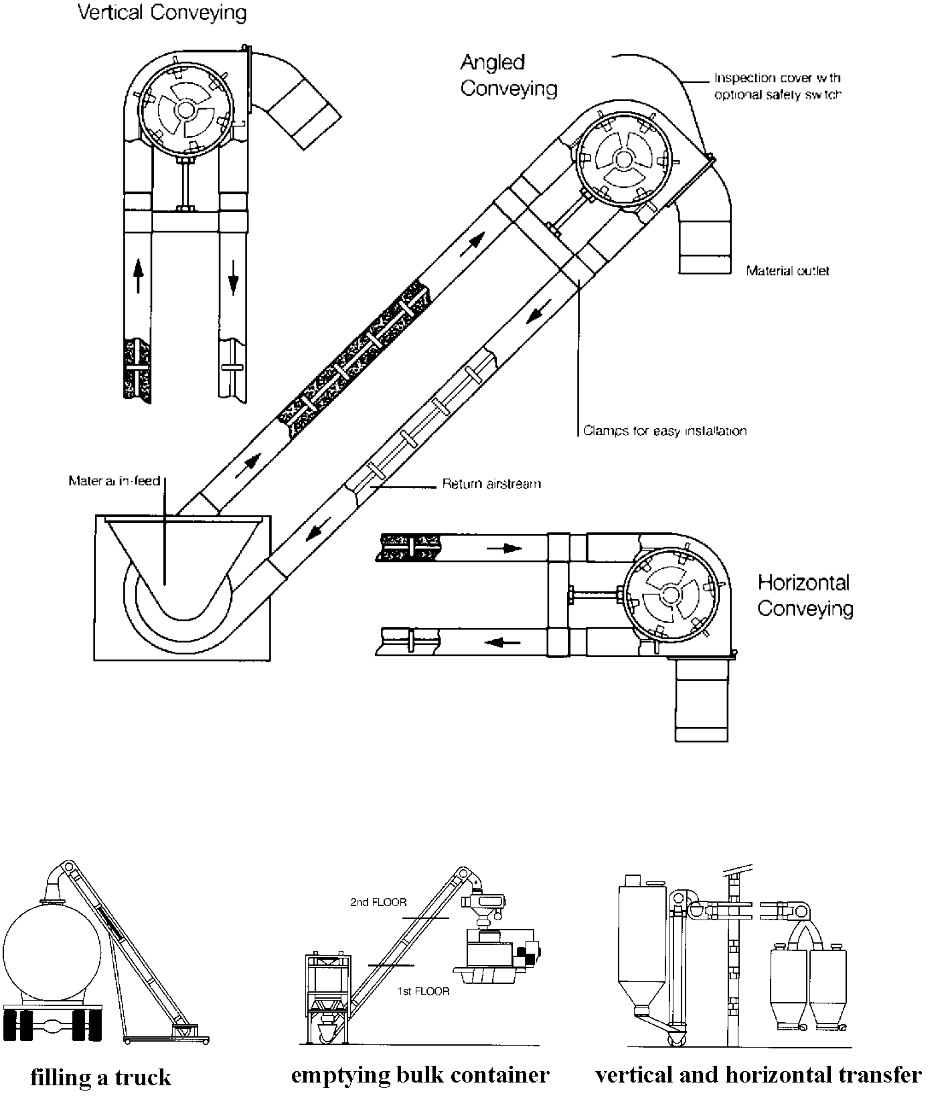

Figure 3.9. Schematic diagram of aero-mechanical conveyor and its applications. Courtesy of Spiroflow-Orthos Systems, Inc., Monroe, NC, USA.

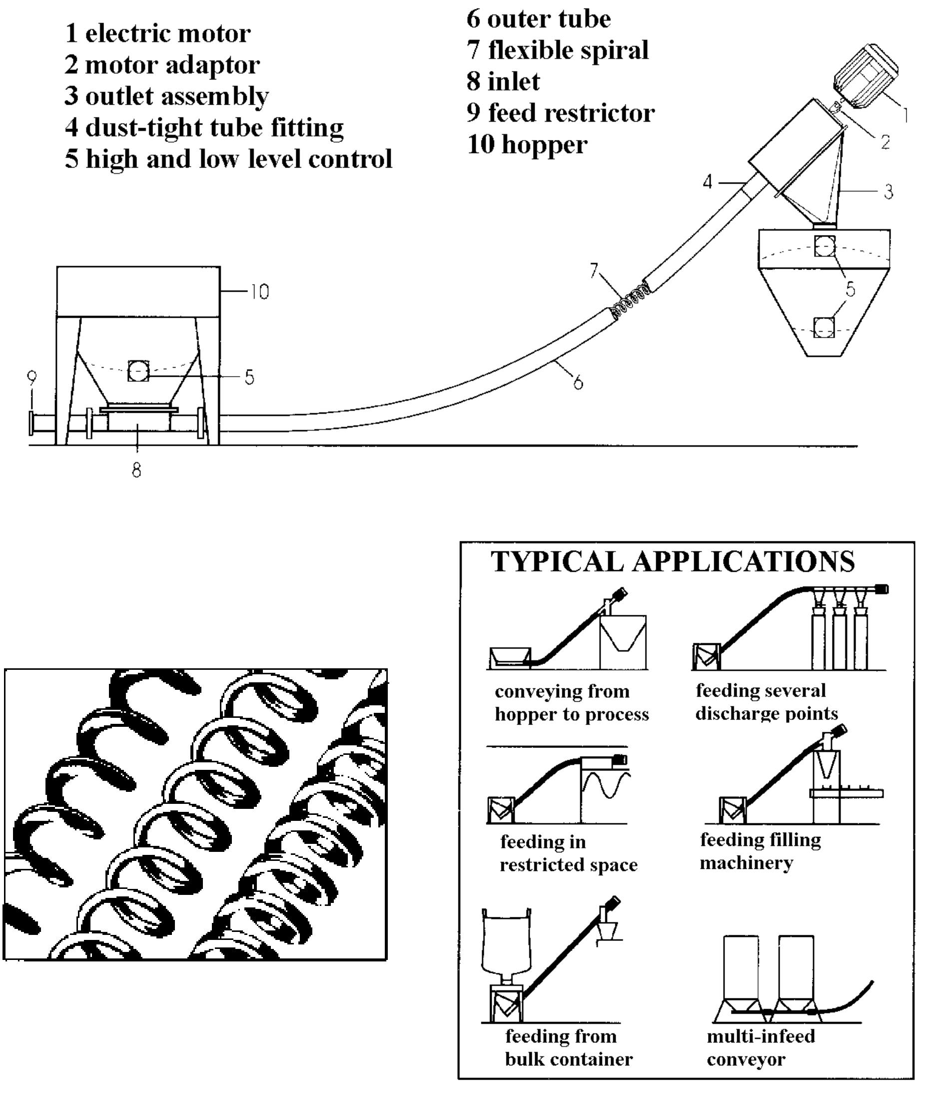

Figure 3.10. Schematic diagram of flexible screw conveyor, spiral design, and examples of application. Courtesy of Spiroflow-Orthos Systems, Inc., Monroe, NC, USA.

The flexible screw conveyor is another system with many advantages. Figure 3.10 shows the schematic diagram of a conveyor and examples of its applications. The only moving part of this conveyor is a flexible spiral directly driven by an electric motor and rotating within an outer tube. The system is totally sealed which makes it dust-free and eliminates atmospheric contamination (e.g., humidity). The spiral’s gentle action does not degrade the material. This conveyor can convey in any direction and with a variable speed

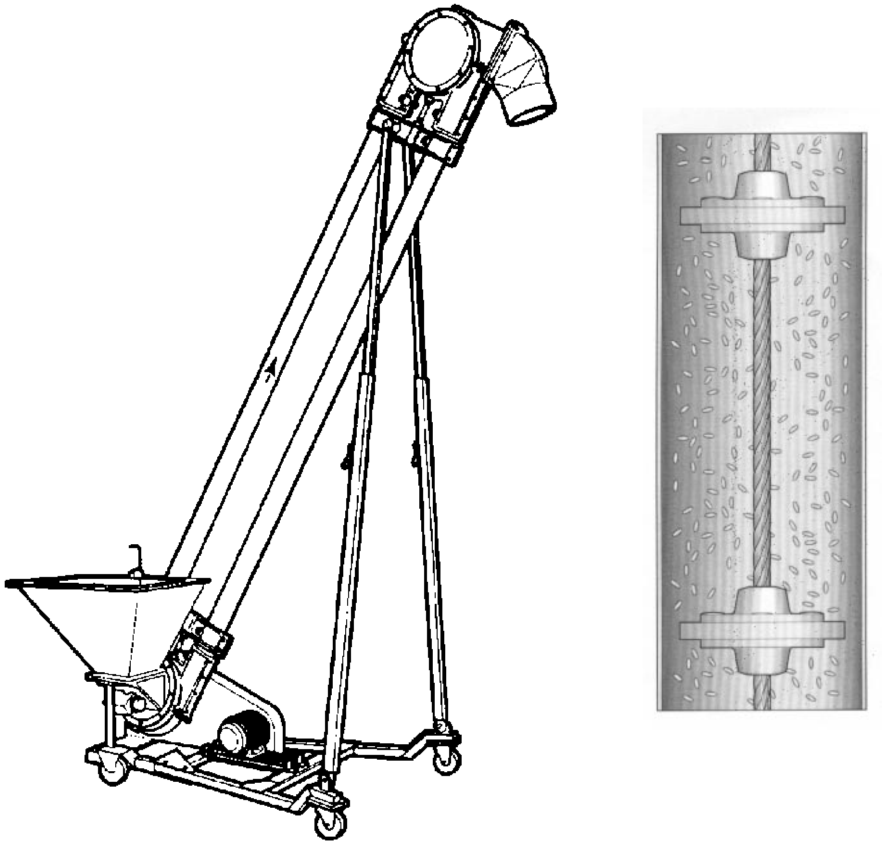

Figure 3.11. AMC aero-mechanical conveyor and the cross-section of conveying element. *Courtesy of Spiroflow-Orthos Systems, Inc., Monroe, NC, USA*.

control accurate metering can be achieved. The simple design is easy to dismantle and clean. Different spiral designs can be selected to move different materials. The conveyor has been used for the following fillers: talc, perlite, calcium carbonate, titanium dioxide, bentonite, zinc oxide, carbon black, alumina, silica, diatomaceous earth, quartz sand, and for many foods, pharmaceuticals, and plastics.

Figure 3.11 shows an aero-mechanical conveying system which is tubular in construction with a tensioned rope fitted with plastic discs. The discs travel at a high rate creating both air and material displacement. This effect fluidizes the product which limits mechanical damage and material segregation by size. The conveyor works in any arrangement (vertical, horizontal, angled) and can deliver numerous fillers to one or to several destinations.

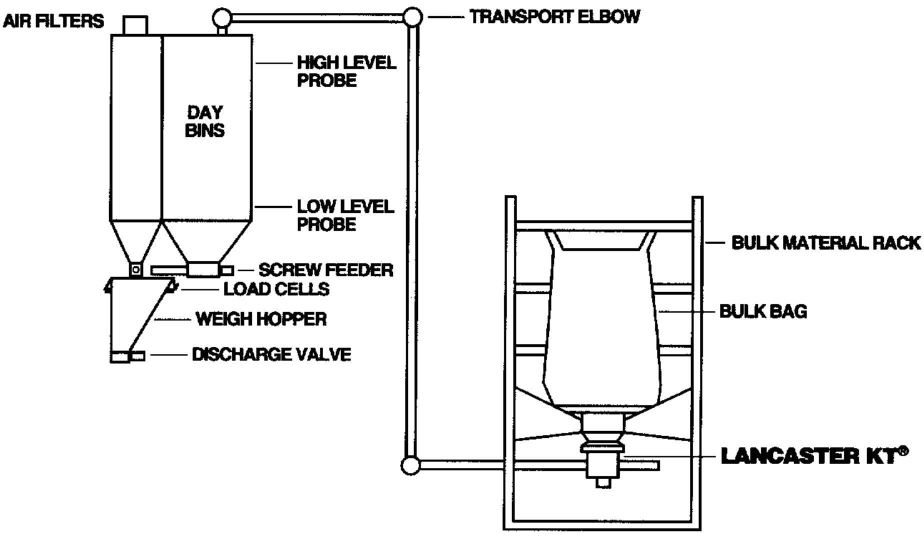

Figure 3.12. Lancaster bulk bag unloader. *Courtesy of Lancaster products, Lebanon, PA, USA.*

3.6 SEMI-BULK UNLOADING SYSTEMS

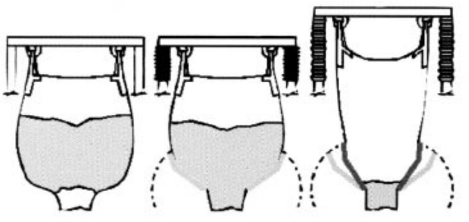

Figure 3.13. Flow-Flexer and Top-Pop bulk bag discharging system. Courtesy of K-Tron Soder, Pitman, NJ, USA.

Due to the environmental protection many powders are delivered in semi-bulk bags. These heavy units require equipment for unloading. Figure 3.12 shows the system for bulk bag unloading to a bin equipped with a weigh hopper to feed.material in a semi-automatic or automatic process.

Figure 3.13 shows Flow-Flexer from K-Tron Soder. During transportation, materials are compacted or lose their fluid properties and will not discharge consistently. Various types of obstruction to the flow occur as illustrated on the left side.

Flow-Flexer bag activators raise and lower the opposite bottom edges of the bag at timed intervals (middle). As the bag becomes lighter, the stroke of the the bottom of the bag into a steep configuration while a Pop-Top bag extension device stretches the bag (right). This device assures complete discharge.

AccuRate developed a combined bulk discharging station and metering unit. This system lifts and positions the bulk bag over a metering unit which can supply material in a known quantity directly to the point of use.

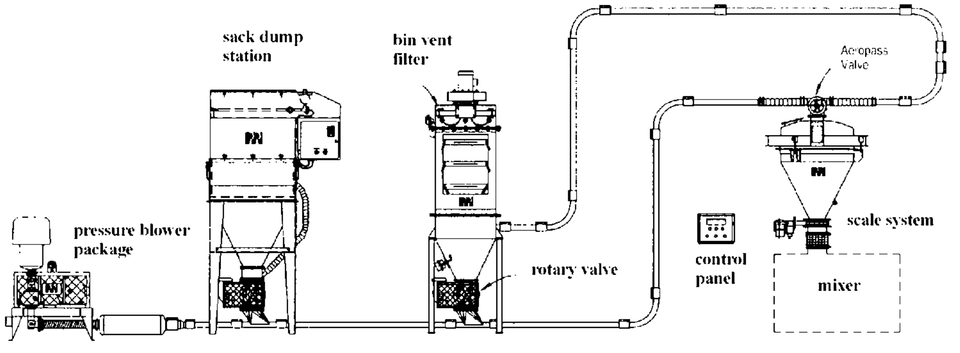

Figure 3.14. Calcium carbonate delivery system from sacks. *Courtesy of Premier Pneumatic, Inc., Salina, KS, USA.*

Palamatic, in addition to designing conventional bulk bag discharging systems, has developed another version called the Duo-Pal Dump Station which combines bulk bag and small bag discharging through a dust control unit.

3.7 BAG HANDLING EQUIPMENT

There are numerous bag handling systems available for filler users. These range from very simple sack dump stations to complicated lines handling up to 600 sacks per hour. The choice depends on investment and volume.

The UK company, Palamatic, specializes in a full range of solutions. A simple sack discharger requires manual bag discharging but with the use of dust extracting equipment which protects personnel from exposure to dust. Such a unit does not have any mechanical parts but is equipped with hood, dust vent, and a grating to place the bag on. A large volume sack handling system is composed of several elements, such as a pneumatic bag lifter, a belt conveyor, a photocell to detect the incoming bag, a sack opener, shaker bars to aid content removal, a sack ejector, a dust extraction system, and a bag compactor. The lines are known to perform with carbon black, titanium dioxide, fumed silica, barytes, calcium carbonate, mica, talc, and other fillers. Palamatic also developed a brush unit to remove dust from the surface of bags. The intermediate systems include semi-automatic and automatic sack opener which eliminates dust leakage and risk of injury. Units are available for the safe discharge of dangerous materials.

Bel-Tyne is another company which specializes in bulk handling systems. The range of equipment includes automatic bag slitting machines, manumatic bag slitters, manual bag opening devices, pneumatic bag lifters, bag compactors, and a complete system which can discharge material from bags to storage or production receivers equipped with metering devices. The automatic bag slitting machine is a compact unit with a short belt conveyor

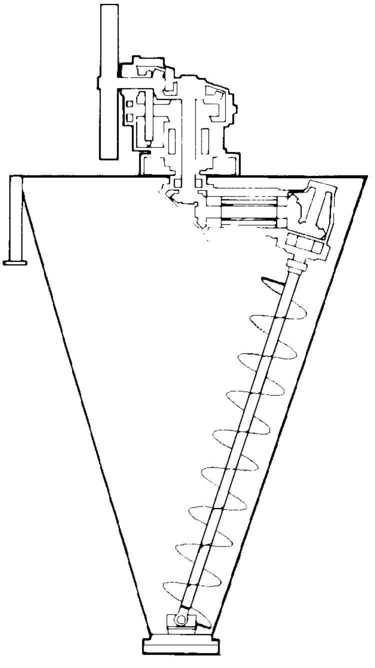

Figure 3.15. Day Mark II mixer. *Courtesy of Littleford Day, Inc., Florence, KY, USA.*

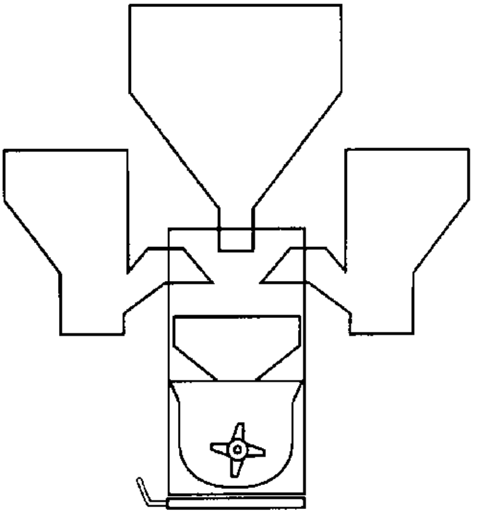

Figure 3.16. NovaBlend design. *Courtesy of Novatec, Baltimore, MD, USA.*

which delivers sacks to a bag emptying unit equipped with a dust control system and waste bag disposal system.

Figure 3.14 shows an integrated system offered by Premier Pneumatic, Inc. for feeding mixer from the sack dump station, trough receiver and metering station.

3.8 BLENDING

Blending of different fillers is a common operation. It may be conducted in one of the two methods discussed below. Littleford Day manufactures a mixer which is useful in the blending operation and many other applications. Figure 3.15 shows the principle of the design. This is an efficient design which can mix up to 4000 lbs of material within 5 min. The screw agitator turns on its axis, producing a lifting action as it spirals the material in an upward flow. The material can be discharged through the bottom or the side. The mixer can be combined with a metering device and used for dosing materials which do not flow well. Other applications include deaeration, vacuum drying, or hot air drying. The unit has a gentle action which does not degrade particles. The mixing action may be increased by the use of a tapered screw design which gives 25% faster mixing.

Novatec developed accurate, sequential metering of up to four materials combined with blending. Figure 3.16 shows the principle of design. The dual load cell under the hopper assures weighing accuracy. Materials are delivered through accurate vibratory feeders. Materials are mixed in the mixing chamber before being delivered to the production unit.

Other designs from Novatec include a gain-in-weight batch blender where 2 to 8 components can be blended together with 0.1% accuracy. During the processing cycle, the operator can view the active filling weight, the actual weight, change formulation, and save formulation. Two hundred formulations can be stored in memory and executed.

3.9 FEEDING

Fillers must be fed accurately and consistently. Frequently, a constant feeding rate is required. The characteristic properties of fillers are particle size, friction coefficients (internal and external), flowability, temperature, moisture content, and degree of compression. Several typical feeders are used. A rotary feeder has several constraints, including a volumetric efficiency decrease as the rotor speed increases and feed rate fluctuation. The pressure of the equipment must be below 2 atm. Screw feeders have a variable range due to powder compressibility; the rate of feed is not uniform. A table feeder has a uniform feed rate and a fast response to changes. Its flow pattern is affected by the scraper and the inclination of the hopper. Belt feeders provide a uniform feeding rate except during belt start up. The rate of feeding and the rate of belt movement have been very well correlated. Other typical feeders include vibrating feeders, valves, and dampers.

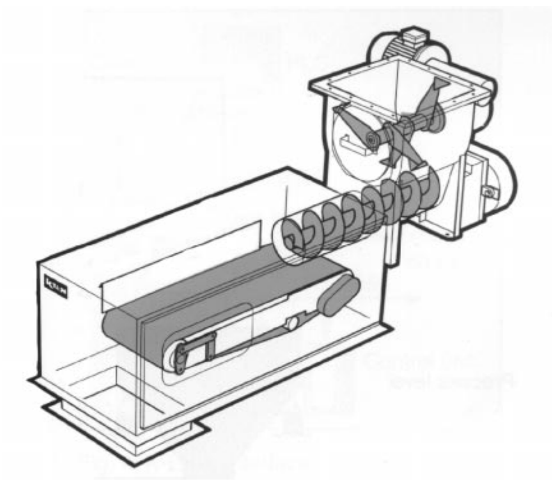

Figure 3.17 Weigh belt feeder. *Courtesy of K-Tron Soder, Pitman, NJ, USA.*

K-Tron Soder specializes in the design and manufacture of feeders useful in dosing and metering of particulate materials. Many solutions are based on their Smart Force Transducer design which gives excellent precision in material weighing. Their range of feeders includes belt, loss-in-weight, and volumetric feeders. Figure 3.17 shows the principle of action of a weigh belt feeder. The feeder schematically shown is designed for poorly flowing bulk materials. The material is delivered to the belt from a hopper or other feed device and is driven through the weight bridge. A computer determines the feed rate based on weight and belt speed. The rate of feed is regulated by belt speed. This type of feeder finds application in feeding glass fibers and glass powders. It delivers material with an accuracy from 0.1 to 1 % of batch size.

Figure 3.18 shows the design principle of a loss-in-weight feeder. The hopper rests on weighing modules which sample the weight remaining and adjusts screw rotation

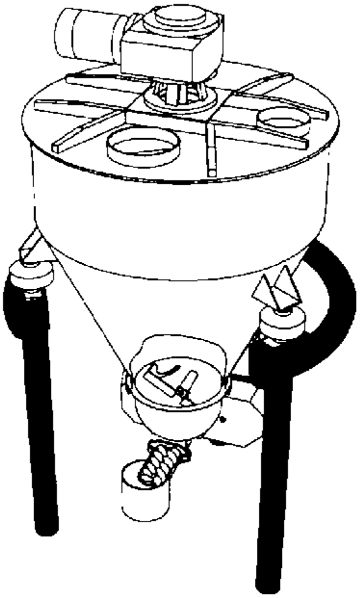

Figure 3.18. Loss-in-weight feeder. *Courtesy of K-Tron Soder, Pitman, NJ, USA.*

accordingly to arrive at the correct feed rate. This feeder can handle a wide range of solid types including free flowing powders, lumpy, moist materials, fibers, and flakes. Figure 3.19 shows the types of screws used to move material. The feeder can move up to 7,000 liters of material per hour. The feeder is microprocessor controlled and can be used in automated designs. It delivers material with an accuracy from 0.1 to 1 %. There are many feeder designs which can be used alone or as part of a multiple unit system. All the feeders discussed above are equipped with a feeder control interface, or a feeder line control display, or a mufti-line feeder control interface.

AccuRate has a range of weigh belts which are designed for both feeding equipment or dosing material to fill containers. The equipment is microprocessor-controlled and its accuracy is improved due to the application of belt influence compensation. The Company also produces a range of loss-in-weight and volumetric feeders which can be used for material ranging from free flowable to difficult to transfer. The materials can be delivered at rates from 15 to 45,000 pounds per hour with a deviation of 0.25% and higher.

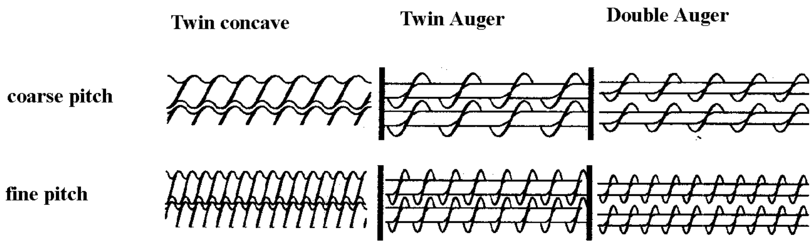

Figure 3.19. Screws used in feeders. *Courtesy of K-Tron Soder, Pitman, NJ, USA.*

Figure 3.20 shows a Multicor Mass Flow Meter which is designed to measure free flowing powders. The material falls on a centrifugal wheel whose rotating guide vanes divert the flow radially outward. The particles moving along guide vanes produce Coriolis

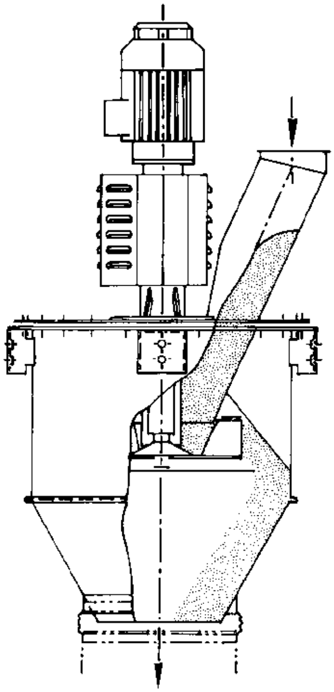

Figure 3.20. Multicor mass flow meter. Courtesy of AccuRate, Whitewater, WI, USA.

forces which generate a measurable torque proportional to the mass flow. These feeders may deliver up 88 tons per hour with metering accuracy and repeatability of 0.5% or better. The feeder is totally enclosed, dust-tight design.

3.10 DRYING

Many technological processes require dry filler. In some cases the moisture level of the filler must be as low as 0.03%. Special drying equipment overcomes the long drying times and ineffectiveness of more conventional drying ovens.

Littleford Day specializes in dryers which use special plow shaped mixing tools which provide a sufficient agitation to filler particles that they form a fluidized bed which is much more accessible to the drying effect of air. In addition, high energy mixing disperses agglomerates. Figure 3.21 shows schematic diagram of a drying system. The heat transfer coefficient is increased two to four times that of traditional paddle dryer. The mixer can be

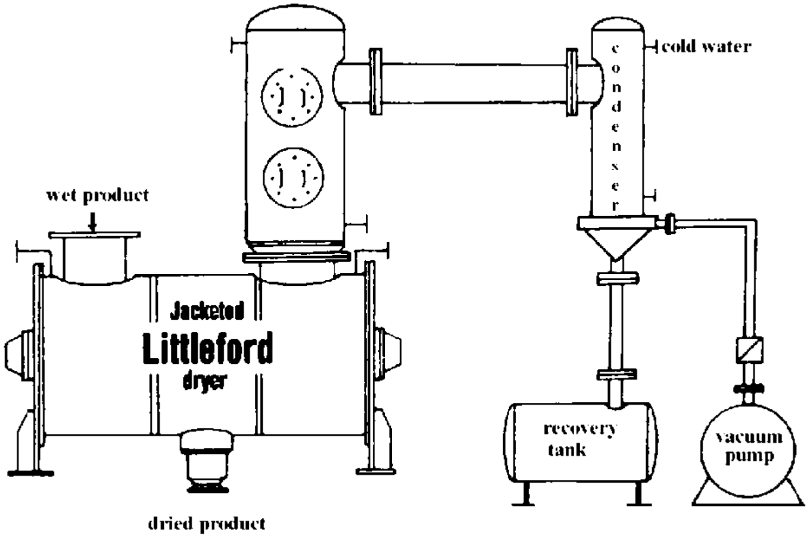

Figure 3.21. Littleford drying system. *Courtesy of Littleford Day, Florence, KY, USA.*

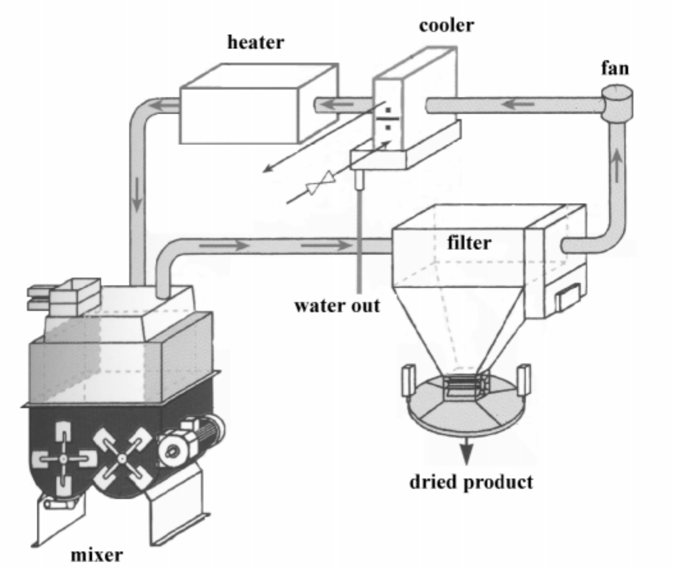

Figure 3.22 Forberg drying system. *Courtesy of Forberg AS, Larvik, Norway.*

operated under atmospheric pressure and vacuum. Mixers are produced in a range of capacities from 300 to 25,000 liters. The mixer has been used for drying the following fillers: carbon black, carbon fiber, iron oxide, molybdenum disulfide, silicon dioxide, and many other pigments and fillers.

Figure 3.22 shows a concept of a drying system developed in Norway by Forberg AS. Although the shape of the mixer and mixing elements differ from the Littleford design the general idea is very similar. Two rotating shafts, each having 14 paddles, create a fluidization zone which enhances heat exchange. The mixer itself is used for other technological purposes and is known to offer extremely short mixing times, from as little as 10 seconds to 2 minutes. The mixer is very economical both as a mixer and as a drying system. It not only saves energy but processes materials without releasing volatiles to the environment. The mixer is produced in capacities ranging from 20 to 5,000 liters. The following fillers have been known to be processed in this system: bentonite, calcium carbonate, calcium sulfate, chalk, clay, ferrite, fibers, fly ash, glass powder, graphite, metal powders, mica, perlite, silica, sand, talc, vermiculite, and zinc oxide.

Novatec has developed two systems which can be applied to drying fillers. One is an indirect gas fired heater which can be used with any drier to improve the process economy. About 80% of the heating cost can be saved by the use of these heaters. Novatec also offers a portable drying/conveying system which conveys particulate materials through the drier and delivers them directly to the next process step.

Drying efficiency can be evaluated by process monitoring which usually requires that a sample be taken from the drier for testing. Favre & Matthijs SA developed a sampling port which allows sampling without interrupting the process either under vacuum or high pressure (Figure 3.23). When the piston is in the upper position, the sampling bottle can be attached. When the piston is lowered, the sample is taken, then the piston is moved back to the upper position, the pressure equilibrated through the valve, and the sampling bottle detached.

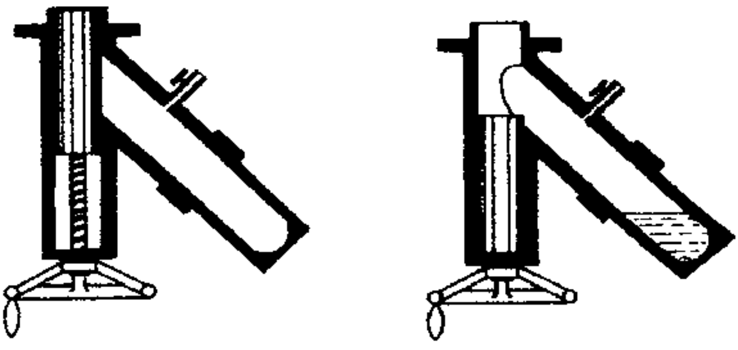

Figure 3.23. Sampling port in closed and opened position. *Courtesy of Favre & Matthijs SA, Lausanne, Switzerland.*

3.11 DISPERSION

Selecting dispersion equipment for a specific application is a complex task. Dispersion of the mixture must be complete and the process and equipment must meet economic constraints. But much more is involved. In practice, such simple criteria are complicated by a variety of parameters related to fillers and to the materials in which they are dispersed. These parameters complicate the problem to the degree that it is not easy to formulate general guidelines. In this discussion we will consider the available equipment types most frequently used for filler dispersion and illustrate their applicability with some examples.

A ball mill is an effective means of dispersing solid materials in solids or liquids.[8,9] Ball mills have several advantages which include versatility, low cost of labor and maintenance, the possibility of unsupervised running, no loss of volatiles, and a clean process. The disadvantages are related to discharging viscous and thixotropic mixtures, and considerably lower efficiency when compared with other mixing equipment. The mill base viscosity is usually restricted to about 15-20 Poise, and therefore ball mills are most frequently found in production applications for paints, flexographic, publication gravure, and letterpress news inks, and carbon paper inks which are dispersed at elevated temperatures.

Several general conditions of ball mill operation should be respected:

- The mill should rotate at 50-65% of the theoretical centrifugal speed in order to allow balls to cascade, since the cascading balls grind most effectively and do not cause an excessive loss of ball material
- The ball load should be 40-58% of the total internal mill volume, and the material to be ground should fill only the voids between the balls (a maximum of twice the ball space)
- Viscosity, the order of filler addition, and the quantity of material should be chosen so as not to cause a viscosity increase above the specified range, since the milling efficiency drastically decreases at that point

- The rotation rate of the mill should be chosen giving consideration to millbase viscosity such that the balls should be carried up to a point between 20 to 30° before the zenith and then cascade down
- The ball diameter should be as small as possible but large enough to permit easy separation from the liquid when discharged
- The wear suffered by the balls generally requires the addition of balls to bring the ball charge up to the correct volume every three months
- If carbon black is to be dispersed, the maximal load of pigment will decrease as particle size decreases because of the effect on millbase viscosity
- The degree of dispersion and jetness achieved when grinding carbon black depends on the wetting properties of the dispersing material and to some degree on the filler form. For instance, pelletized carbon black is easier to disperse than a fluffy type

Sandmills are a logical development of the ball mill idea. In sandmill applications, the following points should be considered:

- The efficiency of a ball mill depends on the number of contact points between the balls
- There is a limit of ball diameter below which centrifuging of mill charge occurs; this limit can only be overcome by a change in the manner of ball movement
- In sandmills, the grinding charge is driven by an impeller. Sand used in such mills has a diameter in ranging from 0.5 to 1 mm; in beadmills, glass beads have a diameter ranging from 1 to 3 mm
- The impeller is mounted centrally in the container and it has several milling discs which rotate at 1,200 to 2,400 rpm
- Advantages include flexibility, ease of operation and maintenance, low contamination, and easy clean-up by solvent washing
- The sand mill has some drawbacks. It is a two stage process (premixing followed by milling). Milling develops high temperatures in the mixture which causes loss of volatiles and requires cooling. If the mill base is high in viscosity or dilatant, the sandmill process may not work at all. Agglomerated or extremely hard pigments are difficult or impossible to disperse
- The practical limit of viscosity is about 20 Poise
- Sand occupies about 50% of the sandmill volume, whereas beads occupy 50-70% of the beadmill volume
- Increasing the volume of the grinding material increases the power requirement and generates more heat; decreasing the volume of grinding material decreases the quality of dispersion
- Dispersion of carbon black is usually done at elevated temperatures in a range from 40 to 150°C
- Inks are generally difficult to feed into a sandmill
- Fluffy carbon blacks can be fed and dispersed without problems, whereas pelleted carbon blacks are difficult to feed
- Some feed problems have been resolved by using a volute type of centrifugal pump and feed tank[3]
- By controlling the ratio of feed to recycle the millbase is kept in constant agitation[8]

Both ball and sand mills operate based on a viscous shear principle, thus the viscosity of the millbase is a critical factor in achieving dispersion. The size of filler particles is critical, especially in sandmills. It was found that the shearing force is inversely proportional to the square of the linear size of filler agglomerate. An agglomerate of diameter of 7 μm attains 100 times the shear stress of an agglomerate of 70 μm diameter. The difference between the ball mill and the sand mill is in the size and density of the grinding media, which is reflected in their performance. Sandmilling uses small particles of low density, and therefore, there is no noticeable reduction in the size of the sand particle, whereas the balls in ballmills are very much larger and may have a high density (steel), which results in a more complex mechanism of grinding including shattering and impacting which cause this mill to be more effective in disintegrating hard particles and agglomerates containing sintered particles.

There is another mill type called an attritor, which is similar to both the ball mill and the sandmill. In construction, it is similar to a sandmill. It also has a vertical shaft, but in the attritor the agitator bars replace the milling discs of the sandmill. It is also similar to a ball mill because it uses balls, usually ceramic ones 5-15 mm in diameter. Because the motion of the balls is independent of gravity, an attritor can handle thixotropic materials and slightly higher viscosity of millbases, but the principle of action and type of forces operating are similar to those of the ball mill. An attritor applied to pigment dispersion gives several advantages. These include rapid dispersion, the possibility of either a continuous or batch process, low power consumption, small floor space, and easy cleaning and maintenance. Their main disadvantage is high heat generation. Attritors are equipped with a cooling water jacket which can control the heat flow to some extent, but conditions are often too severe for some resins, which may degrade during the process.

Three-roll, one-roll, and stone mills constitute a more mature dispersion technology still in use with medium viscosity millbases. A three-roll mill consists of the feed, center, and apron rolls. In roll mill operation:

- The speeds of feed and apron rolls are adjustable, and each roll rotates with a different speed in order to induce shear in the material at the nip and facilitate the material transfer from one roll to the other
- For mechanical reasons the gap between rolls cannot be less than 10 μm and it is usually ranges from 40 to 50 μm.[7] Small particles will not be affected as they pass through the nip, but agglomerates smaller than the distance between rolls will be disintegrated due to the shear stress imposed on the material
- Shear stress depends on such major factors as the relative speed of the rolls, the viscosity of the millbase, and the tack or adhesion of the millbase to the rolls
- Similarly, the transfer of material from one roll to the other depends on roll speed and the adhesion of the millbase to the rolls
- Mill output depends on the distance between the rolls and the viscosity of the millbase
- The three-roll mill can handle viscosities up to 200 Poise, and therefore can be used for materials not suitable for ball and sandmills
- Due to the introduction of easily dispersed pigments and fillers, three-roll mills have lost some of their importance. This may change in the future when solventless systems of higher viscosities become more common
- The one-roll mill works on a similar principle but the nip is regulated by a pressure bar. Shearing takes place between the roller and the shearing bar. Stone mills have similar principles of operation. The rotor turns on a stator to achieve shearing

- With current raw materials, both the primary particles and agglomerates are very small, and if any positive action can be achieved during the milling process, it can only be done by affecting these small particles. It is thus necessary to operate these machines at very tight gaps which causes abrasion of the mechanical elements, rapid deterioration of equipment, and contamination of the product by the abraded material. This affects the properties of the millbase and the color of the product
- Shattering of the agglomerates can in most cases be achieved during the premixing step which is a necessary step before milling with all except the ball mills

The high-speed impeller or shear mixer is the most common equipment to prepare dispersions of solids in liquid. High speed shear mills and kinetic shear mills have retained their usefulness because of their ability to deagglomerate material that is not adequately dispersed in the premixing step. A high-speed shear mill is composed of two elements - a container and an impeller. These factors are important in the design:

- The ratio of the impeller and tank diameters should be no more than 1:3, 1:2-2.5 is the most common. The smaller the ratio, the higher the shear
- Charge depth should range from 1.5 to 2 diameters of the impeller[2]
- The impeller should be located at 1/3 of the charge depth from the bottom
- Rotor speed and speed range are critical
- Turbulent flow (high rotational speed) gives the best results when applied at the beginning of the process
- Deflocculation and deagglomeration require shearing process which occurs in laminar flow conditions
- The final dilution of the mixed material requires turbulent flow for good mixing
- In the first stage, the viscosity changes from low to high as fillers are incorporated; in the second stage, viscosity remains constantly high because of the disintegration of particles which occurs during the application of the highest shear stress
- Long mixing increases temperature and decreases viscosity. This does not provide the conditions for the best filler dispersion. By extending mixing over, for example, a 15 min period, the degree of dispersion is not improved, but the resin may actually be degraded
- If the quality of dispersion is not satisfactory, the parameters of mixing should be changed. If the expected result cannot be attained, the range of conditions available is not adequate in this particular mill
- In the third stage, the viscosity changes from high to low due to the addition of diluent. The viscosity range which can be handled by high speed mixers is similar to the range of a three-roll mill, i.e., up to about 200 Poise

The range of shear rates available in high-speed mixers is not broad. The flow rate of fluid in motion decreases as viscosity increases and is inversely proportional to the width of the flow passage which, in this case, is the distance between the disperser and the container which is very large in a high speed mixer. It is not so much due to an improvement in mixing equipment that high-speed mixers have become so popular, it is mostly because of the high quality raw materials (pigments, fillers) which are available now. High structure carbon blacks can be more easily dispersed. But with the increased structure, the size of the primary particles decreases, inhibiting dispersion. Because of the interrelation between both parameters, only the medium structure, coarser particles of carbon blacks can be dispersed by high-speed mixers. Other carbon black types demand further treatment. It should be noted that this is only true of a few fillers which are known to possess strongly bonded, small sized particles. In most cases, fillers can be successfully dispersed in high-speed mixers. However, care should be taken that the filler is selected with an appropriate particle size.

High-speed mixers have several important advantages over other existing equipment including the possibility of processing a batch in the same vessel, easy cleaning, and flexibility in color changes. The main disadvantage is that the final dispersion depends greatly on the chosen composition and technology, and these are sometimes limiting factors. Frequently, the proper conditions for quality dispersion cannot be achieved at all.

The basic construction of a high-speed mixer can easily be modified to one's special requirements. For example, a change from impeller to turbine rotor changes both the principle of dispersion and the range of application. The tangential velocities of filler particles can be as high as 500 m/sec. Such particles have a very high kinetic energy, sufficient to cause size reduction. Size reduction is due to particle-particle or particle-wall collisions, and this in turn, is related in efficiency to the relative velocities at the moment of collision. Relative velocity can be increased by decreasing the viscosity of the millbase. The upper limit of millbase viscosity is somewhere around 3 to 4 Poise. It is not viscosity alone which is important but the entire rheological character of the millbase. The best results are obtained when the millbase is nearly Newtonian. For this reason, the dispersion process is best performed in a diluted millbase. As is the case with high-speed mixers, a proper dispersion should be achieved in a matter of 10-20 min. If such is not the case, the conditions of processing should be modified. Once dispersion has been achieved, it should be stabilized, with the mixer continuously running, by the addition of more resin to increase the viscosity in order to prevent sedimentation or flocculation of the pigment.

The other possible modification to such a mixer can be achieved by a substantial lowering of the speed and a change in the motion of the mixing element to planetary. This configuration can process material of a much higher viscosity, up to several thousand Poise. The high speed mixer can be modified in various ways to match its capabilities to the process requirements. Stationary baffles may be added to increase the shear rate. The distance between the rotating and stationary elements can be decreased again increasing the shear rate. The mixer may be designed to work under both pressure and vacuum and with inert gas blanketing which permits deaeration and processing of volatile or moisture sensitive materials.

The other group includes heavy-duty mixers, such as the Banbury mixer and double-arm kneading mixers. The Banbury mixer with a power input of up to 6000 kW/m^3 is the strongest and the most powerful mixing unit used by industry. Nearly solid materials are mixed by a rotor which is a heavy shaft with stubby blades rotating at up to 40 rpm. The clearance between the walls and rotor is very small, which induces a very high shear in the material. The high shear generates a great amount of heat which melts the polymer rapidly and allows for quick incorporation of filler. After the filler is incorporated, the dispersion process begins, with rapid distributive mixing along and between two rotors and between the chamber walls and rotor tips. Within 2-3 min, mixing is normally completed and the compound discharged into a pelletizing extruder or a two-roll mill which converts it to a sheet form.[8] Carbon black, which is most frequently processed in a Banbury mixer, is usually placed between two layers of polymeric material in order to reduce dusting.

Double-arm kneading mixers are very popular in some industries. They consist of two counter-rotating blades in a rectangular trough carved at the bottom to form two longitudinal half cylinders and a saddle section. A variety of blade shapes are used, with a clearance between them and the blades and the side walls of up to 1 mm. The most popular blade shapes include: sigma, dispersion, multiwiping overlapping, single-curve, and double-naben blades. It is important for filler dispersion in this mixer that the viscosity of the millbase be kept high enough to create the required shearing force to disperse the material. The strong construction of the mixer and its high power allow one to work with concentrated compositions of pigments which could not be processed by any other method.

High volume production is more and more frequently done by mixing in an extruder.[11,12] This method offers several advantages such as a continuous process, material uniformity, a clean environment, high output, and low labor. The biggest disadvantage of this method is a high investment cost. The twin-screw extruder is the most flexible type of extruder and most appropriate for compounding. Their screw design can be varied as can the method of dosing and the output rate. The abrasiveness of the filler may affect the life-span of the equipment, and particle size and its distribution may influence the quality of filler dispersion and material uniformity. But in general, there is adequate machinery available for almost all requirements. For instance, glass-fiber reinforced materials can be produced by this technique with little change to the initial structure and dimensions of the glass fibers, which shows the versatility of the technology. The production rate of this method is comparable to the Banbury mixer, and an additional advantage comes from the fact that the material can be completely processed in one pass through the machinery.

Finally, one should mention the press mixer, which is a recent development. A press mixer resembles, in its general principle, the high-speed mixer. It has been developed to deal with the high viscosities and heat generated by the mixing process. The mixer has two shafts: one powering the mixing element, called a mixing tool, the other moving one of the container bottoms. The mixing tool is a very strong mixing element occupying approximately 2-3% of the entire mixer volume. This tool can rotate and can be moved with high speed between both bottoms, creating rapid mixing in the whole volume. The bottom moves axially and, because it is well sealed against the side walls, it exerts pressure on the mixed material, increasing the mixing efficiency because the mixing is done on a compressed material. This mixer is suitable for both liquid and solid materials. It is equipped with a method of removal of heat generated during the mixing process. Both the container sides and bottoms and the mixing tool have refrigerant flowing through them which can cool solid rubber by 50°C in a matter of a few minutes. The order of component addition, which is important in other mixers, is less important. The mixer is simply loaded with all components and content is rapidly mixed to the utmost uniformity by the powerful tools provided. The press mixer may even influence the material selection process because it affects the particle size of the filler.

The importance of the proper dispersion of fillers and the complexity of techniques for measuring the degree of dispersion are reflected in numerous publications. Further information on the mixing of fillers is included in Sections 18.5 (dispersion) and 18.10 (mixing).

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