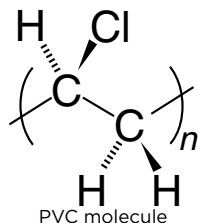


Introduction

Polyvinyl chloride, commonly known as PVC, is one of the most widely used thermoplastics for several good reasons. PVC has an excellent cost/benefit ratio when compared to other polymer resins. In addition, PVC is used in the manufacture of end-use products for a wide range of applications in the consumer, construction, food and medical industries. Products made with PVC exhibit good impact strength, stiffness and strength-to-weight ratio. PVC products offer good dimensional stability at ambient temperatures, resistance to chemicals and oils, durability, and non-flammability character.

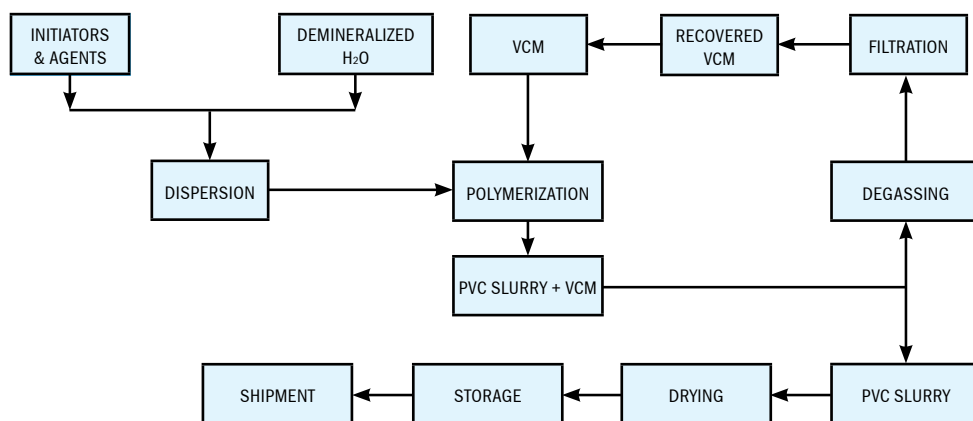
PVC is normally a rigid material that exhibits excellent weather resistance properties. This characteristic makes the resin



suitable for a great number of applications in the building industry. As such, rigid PVC is widely used for window moldings, siding, pipes and fittings that are used outdoors or in the ground. About 50% of all PVC manufactured is used in construction.

With the use of additives known as plasticizers, PVC can be made softer and more flexible and used to manufacture upholstery, hoses, tubing, flooring, membranes, clothing, toys, bottles, inflatable parts such as waterbeds, life boats, life jackets, and many other commercial products.

PVC Production Process



PVC Production

PVC is produced by the polymerization of VCM (vinyl chloride monomer). This reaction is carried out in an autoclave where the raw materials (VCM, emulsifiers and chemical initiators) are dispersed in demineralized water under vigorous agitation. There are four well-known methods for the production of PVC: suspension (S-PVC), emulsion (E-PVC), micro suspension and mass polymerization. The suspension polymerization process is the most commonly used.

In this process, raw materials are added to the polymerization reactor and stirred continuously to maintain the forming PVC in suspension and ensure a uniform particle size. Once the reaction is completed, the PVC slurry that results is centrifuged to remove the excess water. The wet PVC is then dried, sieved and stored or bagged.

Depending on the polymerization method and type of chemical additives used, PVC particles are obtained with different morphology, porosity, bulk density, particle size, and flowability properties. For instance, the average particle

size of S-PVC (100 to 170 µm) is larger than the average particle size of E-PVC (10 to 60 µm) and the flowability of S-PVC particles is higher than that of E-PVC particles. Plastisols are mixtures of emulsion PVC with plasticizers.

PVC Compounding

PVC is a thermoplastic resin that cannot be processed on its own due to its very low thermal stability and high melt viscosity. Therefore, it is necessary to prepare an intermediate product where a variety of additives are mixed with the PVC resin to form a "dry-blend" that can be later melt-compounded or processed into a finished article.

The unit operations present in the compounding of PVC involve delivering and storage of raw materials, feeding and spraying of all ingredients into a special mixer, mixing and heating the materials to create a dry-blend, then cooling and transferring the dry-blend to storage or to a conversion process such as molding, extrusion or calendaring.



Rigid PVC pipe fittings

Material Profiles

PVC

PVC is a thermoplastic with a Glass Transition Temperature (T_g) of about 82°C [180°F] and a density of 1.38 g/cm^3 [86.15 lb/ft^3]. It is an amorphous (low crystallinity), linear molecule with small branches. PVC is the least stable polymer in commercial use. It degrades as it is exposed to UV, high temperature or mechanical stress.



PVC Regrind

Scrap material from the PVC extrusion process is unavoidable. Regrind PVC can maintain the original engineered properties inherent in virgin material. The choice of running 100% regrind material or a combination with virgin material depends on the processing conditions and final part requirements.



PVC regrind

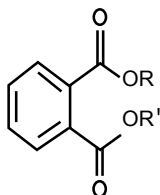
Additives

A large variety of additives is used for PVC compounding. Most additives can be classified in one of several categories including: rework, plasticizers, process aids, heat stabilizers, impact modifiers, fillers, flame retardants, viscosity modifiers, antioxidants, pigments, biocides, antistatic agents, UV absorbers, antifogging agents, and bonding agents.

Plasticizers

Plastics need to be plasticized to enhance their flexibility, resiliency and melt flow. Without the addition of plasticizers, it may not be possible to make plastics sheeting, tubing, film and other flexible forms of plastics.

Plasticizers work by enabling the polymer molecules to move relative to each other with minimal friction. The plasticizer acts as an internal lubricant. A plasticizer can be anything incorporated into plastic but not chemically linked to it. The most common commercial molecules are the phthalates because they offer the broadest range of processing and performance requirements at the lowest cost. The phthalate performance can be fine tuned by altering the alcohol structure of the molecule. Low molecular weight phthalates (those with 1 to 6 carbons in the alcohol backbone) provide lower viscosity and faster processing while high molecular weight phthalates (those with 9 to 13 carbons in the alcohol backbone) provide higher temperature performance and lower volatility.



Where $R, R' = \text{C}_n\text{H}_{2n+1}$; $n = 4$ to 15

Phthalates molecular structure

Heat Stabilizers

PVC is particularly vulnerable to degradation during processing, and is therefore a prime consumer of heat stabilizers. Stabilizers are used to prevent degradation of resins during processing, when melts are subjected to high temperatures. Some common heat stabilizers are zinc stearate, synthetic hydrotalcites and zeolites. Zinc



Plasticized PVC hoses

stearate is a soft white powder that can be easily dispersed during the surface treatment process. Zeolites are aluminosilicates used as adsorbents with flowability problems.

Antioxidants

Antioxidants are used to protect materials from deterioration through oxidation brought on by heat, light, or chemically induced mechanisms.

Flame Retardants

Flame retardants are used to prevent and/or slow down combustion in plastics. The choice of a flame retardant depends primarily on the resin to which they are being added. Flame retardants can be inorganic (e.g. alumina trihydrate (ATH), antimony oxide or zinc borate) or organic (e.g. phosphate esters and halogenated compounds of various types).

Blowing Agents

A blowing or foaming agent is used alone or in combination with other substances to produce a cellular structure in a plastic mass.

Pigments

A variety of inorganic and organic pigments is used in PVC compounding to impart the final plastic part with color. Because of the stringent processing conditions required to compound PVC, the choice of pigments is limited to those that exhibit excellent thermal stability. Similarly, products that will be used in exterior applications require pigments that exhibit excellent light stability.

Titanium dioxide is the most widely used white pigment for a variety of reasons. In addition to its pigmentation properties (brightness, whiteness, opacity, and refractive index), TiO_2 it is also an excellent UV screener. The most common type of titanium dioxide used in PVC compounding is rutile.

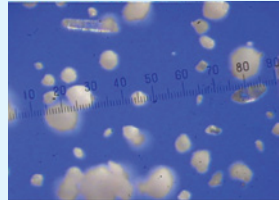
Effect of Filler Properties on Pneumatic Conveying & Feeding

Fillers

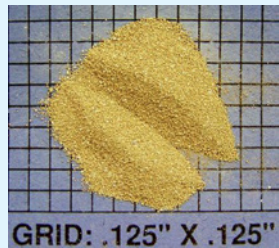
The use of fillers in the manufacturing of PVC parts is very common as they are used to extend the resin, thus reducing the cost of the final plastic part. Likewise, the shape (aspect ratio) of the fillers can increase stiffness, strength and impact performance in the final plastic part. Fillers are also used to add color, opacity and conductivity to a PVC compound. Approximately 80% of the total filler content of a PVC compound is calcium carbonate, followed by titanium dioxide (about 12%), calcined clay (about 5%) and other minerals such as kaolin, talc and mica. The filler's loading, particle size and tendency to absorb the plasticizer influence the production of the dry-blend. For instance, high loadings of fine-grained filler make dry-blends flow less freely, while fillers with a porous surface often absorb too much plasticiser, which in turn results in dry mixes.

Selection of the appropriate filler to use depends on the formulator's objective and the desired properties of the final plastic part. The filler's flowability is determined by the combined effects of the material's own physical properties, external factors such as humidity and temperature and the selection and operating conditions of all solids processing, conveying, and storing equipment. The most important physical properties of a filler that affect its flowability are explained at right.

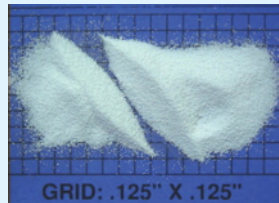
The flow characteristics of each filler determine the type of equipment needed to convey and feed the material in the PVC compounding operation.



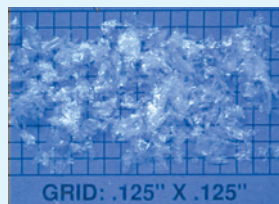
Irregular particle shape with fluidizable, slightly dusty, degradable and segregable characteristics



Irregular particle shape with fluidizable and slightly dusty characteristics



Irregular particle shape with static adhesive, fluidizable and dusty characteristics



Irregular particle shape with interlocking characteristic



Spherical, irregular particle shape with adhesion on impact areas and potential for flooding characteristic

Particle Size & Particle Size Distribution

The average particle size is an approximate measure for bulk flow properties. As a rule, bulk solids flow better with increasing particle size. In small particles ($<20\mu\text{m}$), the relative high surface area to volume ratio causes interparticle attractions that resist bulk flow, whereas in large particles ($>100\mu\text{m}$), the particles have a tendency to roll or tumble and therefore exhibit better bulk flow properties.

The particle size distribution (PSD) of a powder or granular material defines the relative amounts of particles present for each size of particle. In general, a broad PSD enables more efficient particle packing, which may lead to interlocking effects as the small particles fill in the gaps between the contact surfaces of larger particles. Generally, these effects translate into poor bulk-flow properties.

Particle Shape

Filler particles can be found in a great variety of shapes such as cubes, prisms, pyramids, blades, slabs, shells, discs, flakes, spheres, cylinders, rods, or needles. The size of spherical particles is normally given by their diameter. However, most particles are irregular in shape and require the use of different criteria to measure their shape. These criteria could be the particle's limiting dimensions (i.e. length, width, and thickness), the particle's perimeter (i.e. roundness and circularity), and the particle's surface area (i.e. sphericity and bulkiness). The aspect ratio of a particle is one of the most common particle shape criteria and is equal to the ratio of the longest to the shortest dimensions of the particle. Large aspect ratios, such as those encountered in fibers and rods, largely affect the particles' flowability properties and require special handling conditions.

Hardness

Solid particles exhibit hardness or resistance to permanent deformation. Hardness increases as the particle size decreases until a critical grain size is reached. Further cuts in grain size decrease particle's hardness. The intensity of abrasion depends on the hardness, concentration, velocity and mass of moving particles.

Density (Specific Gravity)

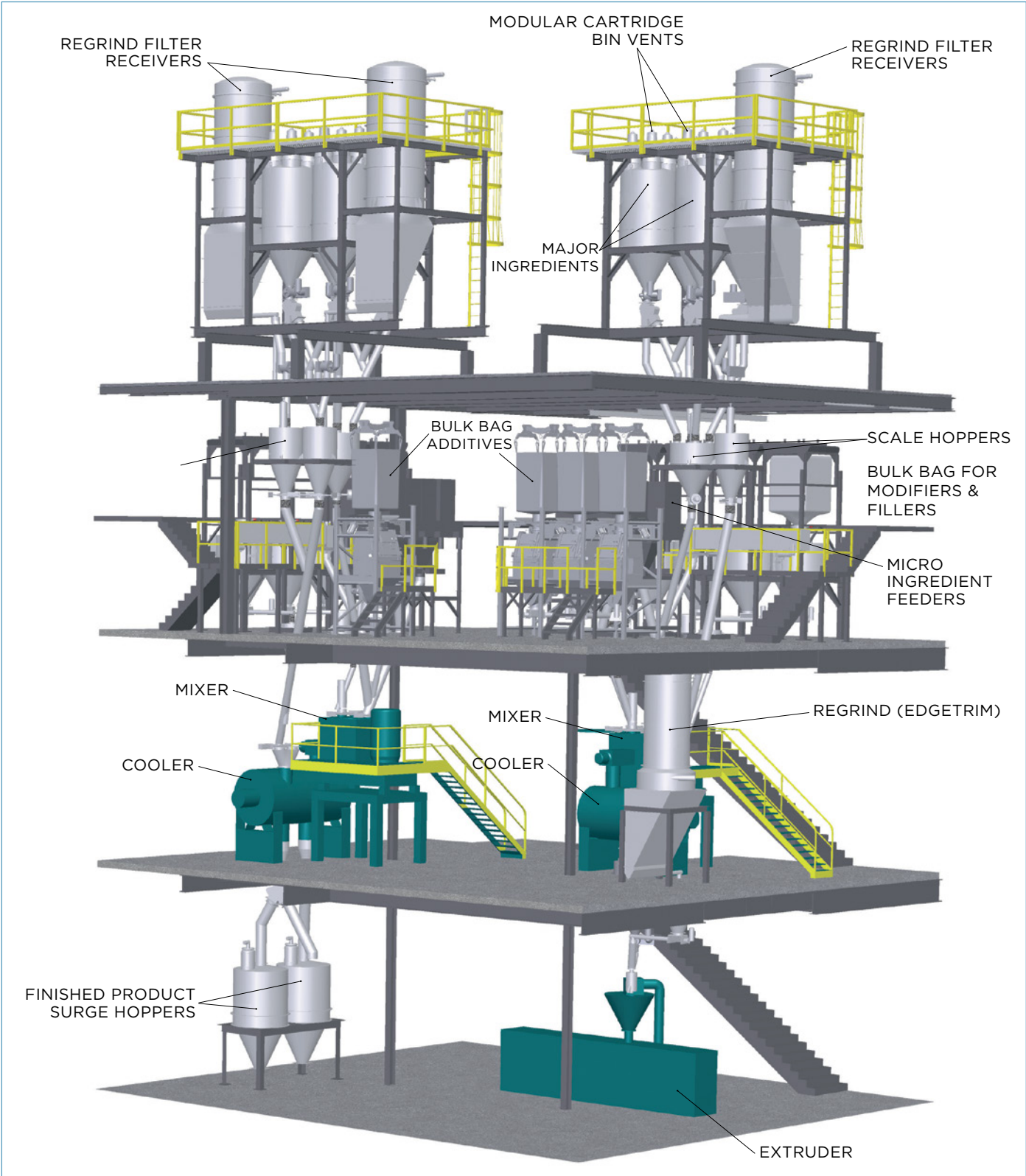
Particle density is a well-defined property, and is not dependent on the degree of compaction of the solid, whereas bulk density has different values depending on whether it is measured in the freely settled or compacted state (tap density).

The Hausner Ratio ($HR = \rho_T / \rho_B$) [where ρ_B is the freely settled bulk density and ρ_T is the tapped bulk density of the powder] is used as an indication of the flowability of a powder. If HR is greater than 1.25, a powder is considered to have poor flowability. Alternatively, the Carr Index ($CI = 100 (1 - \rho_B / \rho_T)$) provides an indication of the compressibility of a powder.

Surface Treatment

Most fillers used in PVC applications are treated with fatty acids (such as stearic acid) or coupling agents (such as silane coupling agents). The objective of the surface treatment is to improve the dispersion of the filler particles during melt compounding and improve the particle's flow properties.

PVC Compounding Plant



Bulk Unloading and Storage Systems

Pneumatic Transfer of Raw Materials

The delivery of PVC resin to a compounding or manufacturing plant is traditionally carried out by rail cars or tank trucks. Tank trucks are equipped with an on-board pressure blower to convey the resin to storage silos. The process of transferring PVC from rail cars to silos is achieved using a combination of pressure and vacuum pneumatic transfer in dilute phase.

In a first step, the material is transferred from underneath the rail car to a receiving hopper. In a second step, a rotary valve feeds the material into a pressure conveying system, transporting it to the storage silo. The dust-contaminated air is filtered and the filters are periodically cleaned with pulses of compressed air.

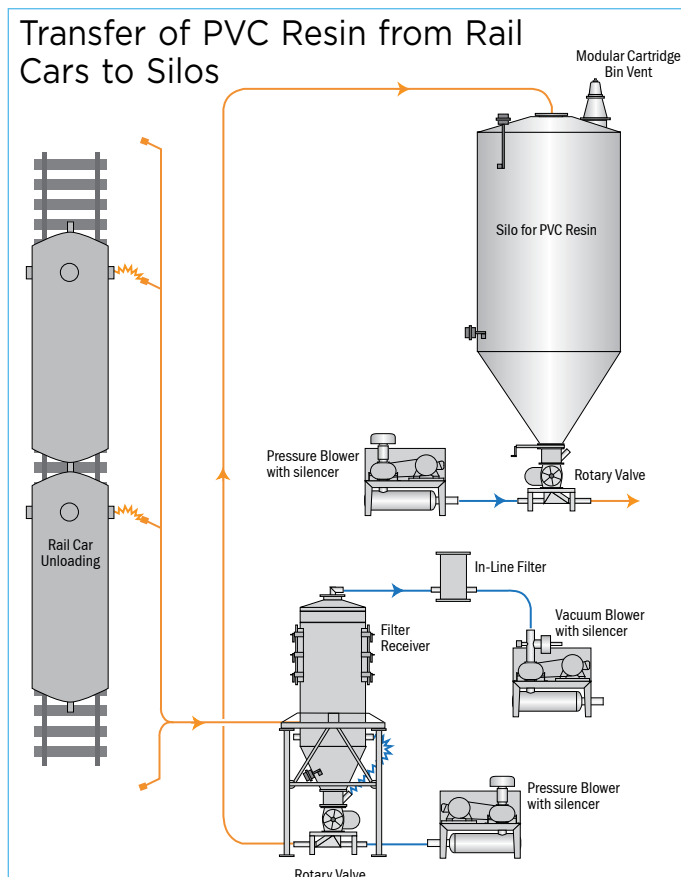
Depending on the size of the operation, fillers such as CaCO_3 and TiO_2 and other additives used in small quantities may be delivered by tank trucks, bulk bags or small bags.

The main raw materials such as resin, regrind and fillers are pneumatically conveyed from storage silos via pressure or vacuum systems to surge bins or scale hoppers situated above the weighing station. At the bins, the materials are separated from the air stream by means of filter receivers. Any airborne material is trapped by the filter's bags which are cleaned by properly timed compressed-air pulses. The filtered material is discharged back to the system.



A Coperion K-Tron continuous vacuum system receiving TiO_2 from a bulk bag unloader and filler from a receiver/surge hopper into a scale hopper.

Transfer of PVC Resin from Rail Cars to Silos



From these surge bins, scale hoppers and bulk bags, the materials are fed via loss-in-weight (LIW) feeders and micro ingredient feeders to a common weigh hopper.

Fillers and regrind are conveyed with vacuum or pressure conveying transport to receiver bins and fed with rotary valves or other dosing valves into a collection hopper mounted on load cells. The dosing valve slows and then stops when the material weight equals the recipe value.

Choosing the Right Feeder

The choice of raw materials, the size of the compounding operation and an end-product formula or recipe, determine whether the material is fed gravimetrically or volumetrically, the type of feeder used (single or twin screw or rotary valve), and the order in which the materials are added to the high-intensity mixer.

Rotary valves are the most common feeders for fillers and other ingredients in situations where high accuracy is not critical to the process. Coperion K-Tron offers a wide range of rotary valves with a variety of options available, depending on the material to be fed.

The flow characteristics and desired throughput of each bulk material determines the type of feeder and the type of screws used. Depending on the flow rate, free flowing powders can be fed with a single screw feeder, while poorly flowing powders are generally fed with a twin screw feeder.

Spiral, concave or auger screws are used, sometimes with supplementary vibration or concentric spirals in the inlet to break up the product. A horizontal agitator in the feeder bowl prevents bridging and moves the powder to the discharge screws.

State-of-the Art Feeding and Metering Solutions

While volumetric feeders are often sufficient for delivering ingredients to a process, gravimetric feeders become a necessity wherever the accuracy of the feed rate is critical. This is the case when small amounts of additives or expensive raw materials are called for in a formulation.

Coperion K-Tron has a wide range of gravimetric and volumetric feeders to handle a myriad of raw material components in powder, granular, pellet or paste form.

Feeding, Blending and Metering

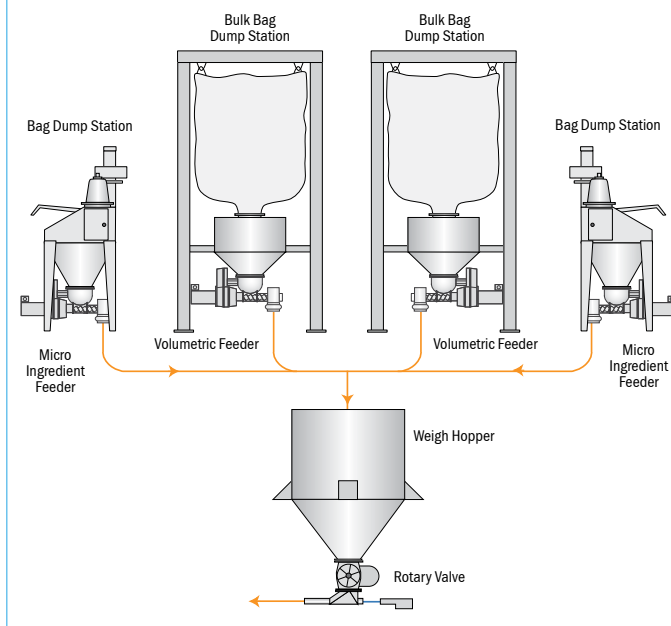
In batch feeding operations, all materials are metered in Gain-in-Weight (GIW) batch mode. GIW batching uses individual volumetric feeders to feed ingredients into a common weigh hopper. A batch cycle is generally made up of two phases; during the first phase, 90% of the batch weight is fed as fast as possible. During the second phase, the last 10% of the batch weight is fed in a slower “dribble” mode to ensure an accurate result in achieving the weight setpoint. When the setpoint is achieved, the feed is stopped.

GIW batch conveying is another precise and economic way of weighing. The main component, PVC base resin powder, is transferred with a pressure or vacuum pneumatic conveying system to a scale hopper mounted on load cells. A diverter valve mounted on top of the scale hopper guides the material into the hopper. The material accumulates until the target weight is reached, at which point the diverter valve is switched back into closed position and excess material in the line continues on to the next scale hopper or back to the source.

Liquid raw materials are often quite viscous and their flowability often changes with temperature fluctuations. For these reasons, liquids are transferred with positive displacement pumps (piston or gear) to GIW scale hoppers.

A combination of GIW and LIW modes is possible, especially if concentrates, blowing agents or small amounts of other ingredients are required. LIW feeders are equipped with very accurate load cells to achieve high weighing resolution. The size of the

GIW Feeding of Minor Additives



LIW feeder bowl, hopper and screws is determined by the flowability properties of each material.

Once all relevant additive components have been transferred to the collection hopper, the mixture is ready to be emptied or conveyed into a high-intensity mixer.

Dry-Blend Production

The intermediate compound known as a ‘dry-blend’ is generated by mixing together the ingredients according to predetermined formulations. The different materials are brought together in a high-intensity (high speed) hot mixer. The components are fed into the hot mixer in sequence to avoid temperature degradation of any material.

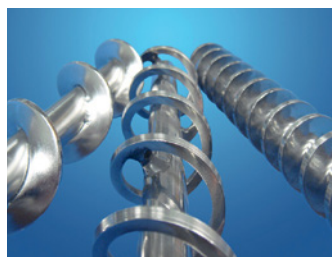
The principal ingredients of PVC dry-blends are PVC resin powder, fillers, additives and rework. If the dry-blend contains a plasticizer, it is referred to as ‘PVC-P’ and if it does not, it is referred to as ‘PVC-U’.

The friction-generated heat melts the solid components into a gelled material which allows the absorption of the liquid plasticizers. The hot mix (approx. 110°C to 130°C [230°F to 266°F]) is transferred to a much larger, water-cooled low-intensity mixer until a temperature of 50°C [122°F] is reached.

For large scale operations the dry-blend may be fed directly into the processing equipment. In contrast, for small scale operations or when a high degree of homogenization is required, it is necessary to first compound the dry-blend into pellets. Traditionally, this operation is carried out in twin screw extruders.



S60 Single Screw Loss-in-Weight Feeder



The type of feed screw is selected based on the bulk material's characteristics

Extrusion and Molding

After emptying the material from the cooling mixer into an intermediate hopper located underneath the mixer, the material is transferred by means of a pressure conveying line into storage silos to be processed in house. Static silo blenders, such as the Coperion K-Tron ProBlend™ Zone Blender, can be used to remove any batch-to-batch variability. The dry-blend is then either conveyed to a processing line or packaged in bulk bags to be sold. Typical end product processes are extrusion of siding, pipes and other profiles or granules for the cable or injection molding industry.

Systems Engineering

The design and construction of a PVC compounding and extrusion plant is a complex engineering project, which can range from a simple inquiry for a plant expansion or modification to the construction of a new facility. In any project, from the initial concept to the plant operation, there are a large number of variables that must be considered and handled correctly for the complete success of the project.

PVC compounds use a myriad of innovative materials and sophisticated chemistry to formulate their products. The challenges posed by abrasive, friable, sticky, moisture and temperature sensitive, hazardous, hard-to-filter, prone-to-oxidation and poorly flowing materials often seem overwhelming. While the chemical properties of each component are, no doubt, at the core of the product's success, an

optimal bulk material handling system is at the center of the operation's profitability, as it allows for increasing production and plant efficiency while decreasing labor, material and energy costs.

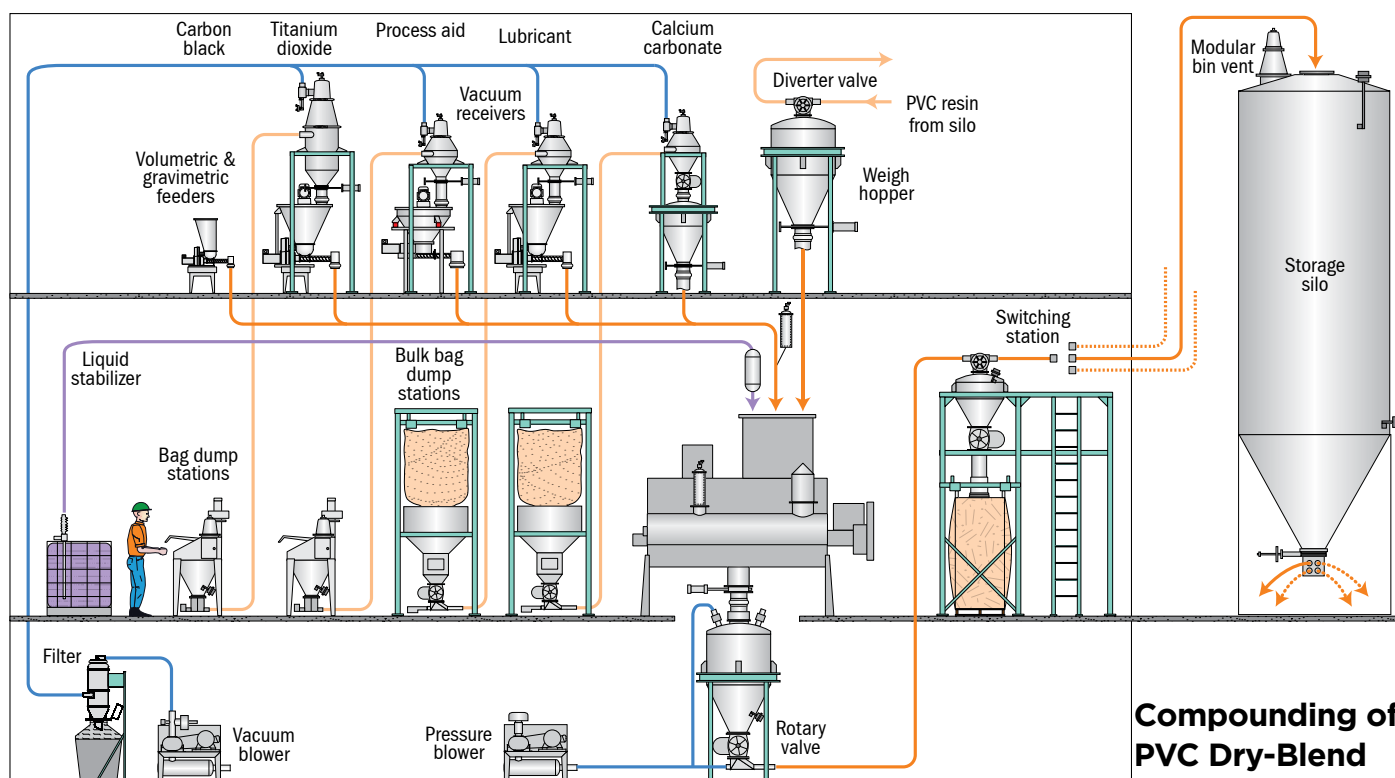
The engineering of such a complex system calls for know-how and experience not only in materials science, but also in pneumatic conveying systems (pressure and/or vacuum), bulk unloading and storage systems, and weighing and scaling systems, including full integration with feeders and blenders, heaters and coolers, dehumidifiers and dryers, filters and a wide variety of other auxiliary equipment.

A dedicated Coperion K-Tron Systems Engineer provides an interdisciplinary approach to PVC compounding projects, centering all activities first and foremost on the customer's business and technical needs. The

systems engineer is responsible for gathering information, developing the concept and design, preparing and presenting the proposal, overseeing the design and manufacture, commissioning and starting up the project and training the customer's personnel on the proper operation of the equipment. From beginning to end, the project is handled by one individual; a single point of contact approach to systems engineering that is highly valued by our customers.

Controls

Large or small, a PVC compounding operation must deliver accurate amounts of a large number of ingredients to produce dry-blends with good reproducibility. Sophisticated recipes call for the timely addition of exact quantities of difficult-to-handle addi-



Custom-Tailored System Design

tives. Any errors translate into scrapped product, productivity loss, and poor quality products that affect the customer's good will and may end in potential liabilities.

Process control systems integrate the operation of individual pieces of equipment and synchronize their operation to the benefit of the entire plant. They can even be as complex as a Human Machine Interface (HMI) with displays and controls of the entire PVC compounding operation, a particular process zone (e.g. silo loading) or a piece of equipment (e.g. vacuum sequencing in a silo loading operation).

In a PVC compounding and extruding operation, there are three distinct areas where the use of process controls significantly enhances the efficiency of the operation: in the conveying of raw materials from trucks and rail cars to silos and their subsequent in-plant transfer, in the feeding and precise weighing of all ingredients that make up the PVC formulation, and in the transfer of the homogenized dry-blend to the extruder.

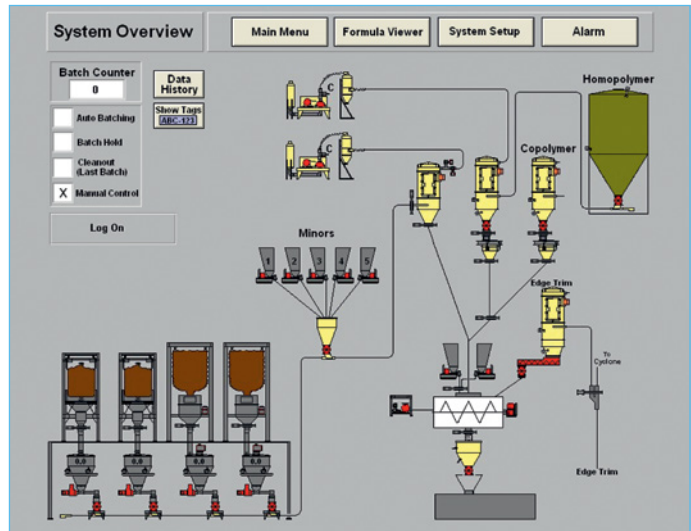
In the conveying of raw materials, control automation helps verify inventory and location and notify vendors when to resupply raw materials. Controls ensure the appropriate flow rates, weights, pressure drops, and temperatures.

In the feeding of ingredients, controls store and recall formulation recipes, feed all ingredients accurately into the high intensity mixer and control the time and temperature of the blending operation. After the dry-blend has been cooled down in the low intensity mixer, controls ensure the timely transfer of the dry-blend to the extruder.

Process controls initiate and verify production runs, control auxiliary systems, and alert for inconsistencies and faults. They keep accurate production records, records of database access and modifications and alarm histories. A touchscreen Human Machine Interface (HMI) or Graphical User Interface (GUI) generally includes color graphics with alarm displays that are customizable to individual systems and include the ability to transfer data over a network connection for storage and remote troubleshooting and support.

Coperion K-Tron's Capabilities

- Pre-engineering team capable of interpreting complicated engineering specifications and quoting accordingly
- Proven project management skills



A highly automated Human Machine Interface (HMI) provides complete recipe management as well as control of the mixer and cooler

- Established international partners as sub-vendors around the globe
- Experience & know-how handling challenging powder additives
- Experience in design and implementation of nitrogen closed-loop systems
- Comprehensive product line with all necessary accessory products such as filters, level indicators, diverter valves, rotary valves, coolers, piping and blowers
- Experience loading into transport forms such as sea/land shipping containers, trucks, railcars, boxes and bags
- Experienced Global After Sales Service network with factory trained and certified engineers
- Service engineers familiar with working in harsh environments

