FEED ENHANCEMENT TECHNOLOGY FOR LOW BULK DENSITY MATERIAL INTO CO-ROTATING TWIN-SCREW COMPOUNDING EXTRUDERS

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Abstract

Effectively feeding low bulk density material into a co-rotating twin-screw extruder has always been a challenge. However with the introduction of even finer particle size fillers (sub-micron in some cases) as well as new generations of polymer reactor resins, the issue has become even more problematic. Additionally as bulk density decreases, the materials tend to fluidize more easily. Fluidization lowers the "effective" bulk density even further and exacerbates feeding issues. Typical unit operations within the compounding process where material is more susceptible to fluidization are: transfer from storage vessel to feeders, from feeder to twin-screw extruder and within the feed zone conveying section of the twin-screw extruder. While there are methods to minimize the potential for fluidization such as dense phase conveying from storage to feeder, minimization of the feeder height above the extruder feed opening, incorporating a vent into the feed hopper, extending the length of the conveying zone in the extruder feed section, the process eventually reaches a feed volume limitation, which more often than not is well below an economically viable production rate. This paper will review a new Feed Enhancement Technology (FET) that provides significant improvement for the introduction of fine particle / low bulk density materials into the extruder.

Introduction

Effectively feeding low bulk density material into a co-rotating twin-screw extruder has generally presented a challenge to compounders. Andersen [1, 2] reviewed many of the "standard" techniques used by compounders to stave off the onset of a feed volume limitation. These include but are not limited to dense phase conveying from storage to feeder, minimization of the feeder height above the extruder feed opening, incorporation of a vent into the feed hopper, use of higher pitch elements (2 times extruder diameter), use of increased free volume undercut profile "pushing" SK type elements in the feed opening, and extending the length of the conveying zone in the extruder feed section. Kapfer et al. [3] reviewed the advantages of using an extruder with a greater outer diameter to inner diameter ratio (D_o/D_i), i.e. deeper channel screw elements and therefore more free internal volume per unit length. However improved solids conveying does not result solely from the deeper screw channels. At the same time as the D_o/D_i increases. the angle of the conveying flight profile with respect to the axis of the screw gets closer to 90° (vertical, i.e. more like the previously mentioned undercut SK elements) and the resulting pushing force has an increased down channel component, i.e. it is more parallel to the longitudinal direction of the screw. However, even with utilization of the previously noted techniques as well as an extruder with an increased free volume geometry, the process eventually reaches a feed volume limitation, which more often than not is well below an economically viable production rate

Over the past several years utilization of small particle size lower bulk density fillers, as well as the demand for improved productivity for finishing lines processing polyolefin reactor resin powder, has increased. Consequently, the issue of feeding fine particle materials at an economical rate has become even more challenging. For example, even if the compounder is able to introduce the fine particle material at the maximum bulk density possible, i.e. minimal included air, as the mass of particles are being compressed and transformed into a melt, the remaining included air is released. The only way for this air to exit the compounding line is to flow counter-current to the incoming material. This is not an issue for pellets. However, the lower the bulk density of the entering feedstock or filler, the more easily it tends to fluidize. This results in an even lower "effective" bulk density which further exacerbates feeding issues.

Scale up is another key issue impacted in processes feeding low bulk density materials. The general guideline for scale up of a polymer compounding process is that the rate increases by the ratio of the diameter cubed of the larger vs. smaller extruder. If one were to scale from a 50 mm to 100 mm compounding extruder, the expected scale up would be 2^3, or 8. However, the x-sectional area increases only be the square of the diameter, in this case, 4. Therefore, a higher backflow air velocity countercurrent to the incoming feedstock would be required to eliminate all the included air. This will further exacerbate feeding. Even if a process appears to have no fluidization or feed limitation issues on a lab or development line, there could be issues on scale up.

Feed Enhancement Technology, FET, is an advancement of the conveying portion of feed system design that provides significant improvement for the introduction of fine particle and low bulk density materials into the extruder.

Feed Technology Variables

The objective of any feed enhancement technology is to improve the effective coefficient of friction between the material and the barrel wall in the solids conveying section of the extruder. As shown in Figure 1, the solids conveying capacity is a function of several factors which are interrelated in various combinations. For example, the free cross-sectional area (F) of the extruder, the pitch of the element (H), and the rpm (n) determine a "theoretical" conveying factor. The bulk density and the fill factor combination is an indication of the potential for material in the solids conveying section to fluidize. That is, fluidization potential increases as either the bulk density drops and or the degree of fill approaches 1. In the former there is more air to be eliminated in the feed zone and in the later as the unfilled cross-section of the screw profile is reduced, the escaping air velocity increases and enhances the probability of fluidization. Another interesting point is that as the degree of fill in the feed section approaches 1, rpm has a negative influence on feed intake. For example, the rate/rpm flood point decreases as rpm increases, i.e. the higher the rpm, the more the feed material is fluidized. Finally, the conveying efficiency is directly proportional to the "dynamic" coefficient of friction, the higher the coefficient of friction, the greater the conveying efficiency. It is important to note that neither the actual bulk density of material nor the actual coefficient of friction in the conveying section can be accurately determined from static feedstock measurements.

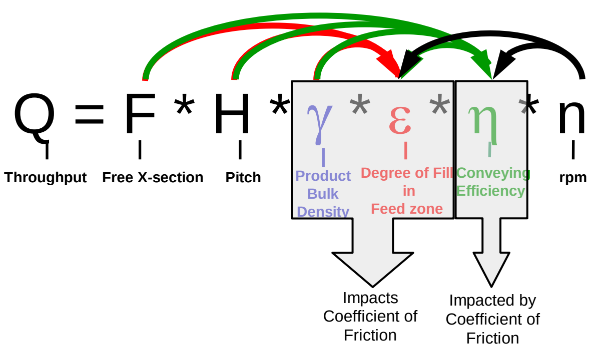

Figure 1: Solids conveying variables in a Twin-screw

Relative conveying efficiency for a feedstock can be approximated by measuring the material flow angle (conveying angle) for a particular pitch element. Figure 2 illustrates this point. The larger the conveying angle (b), the more the material is being transported in the axial direction rather than the circumferential. Thus if the coefficient of friction can be increased, the conveying angle and therefore conveying capacity will increase. The maximum conveying angle for an element occurs at the point where the conveying direction is orthogonal to the helix (c).

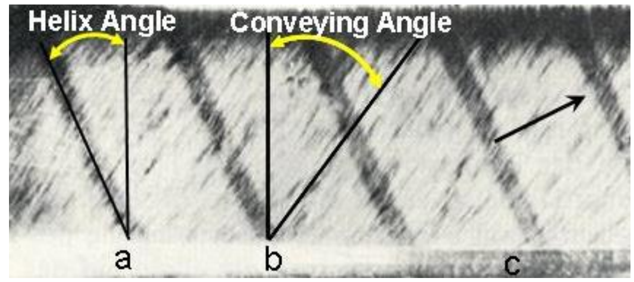

Figure 2: Helix or pitch angle (a), Conveying angle (b) for powder, maximum conveying angle (c).

Feed Enhancement Technology

The objective of FET is to increase the feed intake / feed zone throughput capacity for difficult to feed materials by improving the conveying efficiency through an increase in the coefficient of friction between the feed and barrel wall i.e. minimize/eliminate wall slip.

The conveying efficiency / coefficient of friction increase is achieved by "adhering" a layer of feedstock material to a portion of the barrel wall through the application of vacuum to a specially designed section of the barrel wall in the feed zone which is porous and permeable to the gas, but not to the feed product. Therefore the pore size of the porous section of the barrel wall relative to the particle size of the powder is very crucial. Additionally the optimum vacuum level applied to the device depends on particle size and shape of the feedstock. If particles were to penetrate the pores, the efficacy of the process would be reduced. However, if powder were to penetrate the pores it could be back flushed out by applying a pressure through the vacuum line(s). While powder infiltrating the porous barrel wall could be problematic, even more critical would be the presence of polymer melt or other fluid. Both of these materials would smear over the porous surface or even penetrate the pores and clog the porous structure.

While it would be possible to construct an entire barrel from a porous material, the more economically viable solution is to install an insert (or inserts) made from or containing the porous material into an "open" style barrel. This insert design concept provides additional benefits. First, the insert can more easily be continuously and intensively cooled to avoid melting of the compacted polymer powder filter cake layer or any particles that may infiltrate the pore structure. Second, in the unlikely event that the unit would become damaged, it can more easily and cost effectively be replaced.

The working principle of FET is illustrated in Figure 3. By applying the vacuum through the porous material, air surrounding the polymer or filler is evacuated as it passes the FET barrel section insert. As the air is sucked toward the insert, it entrains and carries the particles toward the insert surface. The air goes through but the material remains behind to coat the surface. This coating, or filter cake, of densified polymer powder has the effect of increasing the coefficient of friction between the wall surface and the bulk of the material. The layer of material adhering to the barrel wall due to the vacuum is continuously renewed by the rotating screws. Additionally, the bulk density of the powder is increased as it passes the insert. These two effects combine to improve the conveying efficiency.

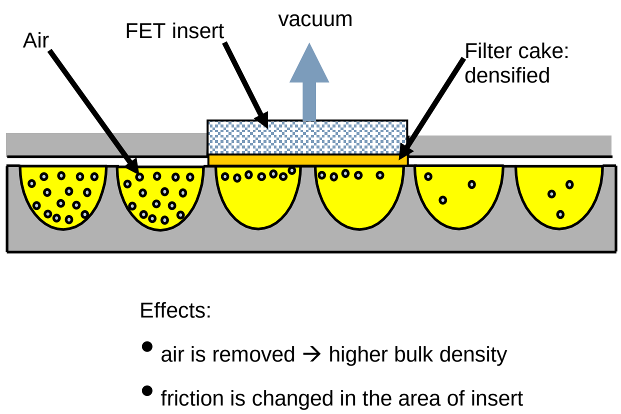

Figure 3: FET operating principle

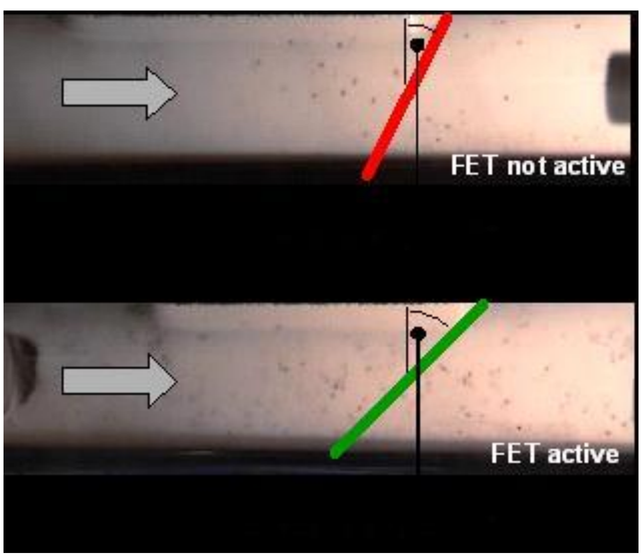

Figure 4: Improved conveying angle with activation of FET

Figure 4, illustrates the impact of this technology. The conveying angle improves significantly with engagement of FET.

Machine Configuration Options

There are several options for location of the FET insert, Figure 5. It can be installed upstream of the feed location and be used as a back vent for feed stocks containing pellets. It can be installed downstream of the feeding point but before the melting section. As mentioned previously, because of the nature of the filtration medium, the FET can only be used in the solids conveying section. It can not be used at any point where there is a melt. Finally, to accommodate use of the technology for introduction of filler in the downstream portion of the extruder, the FET insert can be installed in the barrel of a side-feeder.

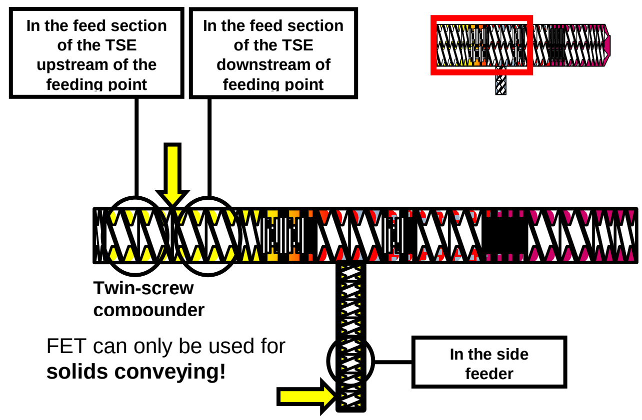

Figure 5: Installation options for FET

Experimental Set up / Results

To verify the viability of the technology, the three system set up variations were evaluated. The downstream configuration (FET insert placed in main extruder barrel section downstream of the main feed location) was evaluated for an HDPE powder resin. This was first run in the lab, but subsequently the system was installed on a ZSK 240 production unit. The result was that the throughput rate was increased from 14 to a torque limited 17 t/hr.

The back vent version (FET insert placed in main extruder barrel section upstream of the main feed location) was tested in the lab but then installed on a 92 mm production line for an HFFR (Halogen Free Flame Retardant) material. The upstream feed was a blend of polymer, ATH and additives being fed into barrel 2. Additional components including oil and a second ATH addition were introduced subsequently in the downstream portion of the line. The result was an increase of more than 50% from 1.4 t/hr to over 2.2 t/hr. In addition to the increased rate, this set up also eliminated powder leakage back through the packing between the first barrel and the lantern.

The most typical use for the device is to enhance productivity for highly loaded mineral filled compounds. For these materials the most common set up for the technology is to install the device in the side-feeder. Figure 6 illustrates a typical set up for these materials. Note that for most efficient performance the side-feeder has inserts on both the top and bottom of the barrel. Figure 7 shows the modified side-feeder containing the FET unit (arrow). The vacuum connections are attached to the top and bottom of the barrel.

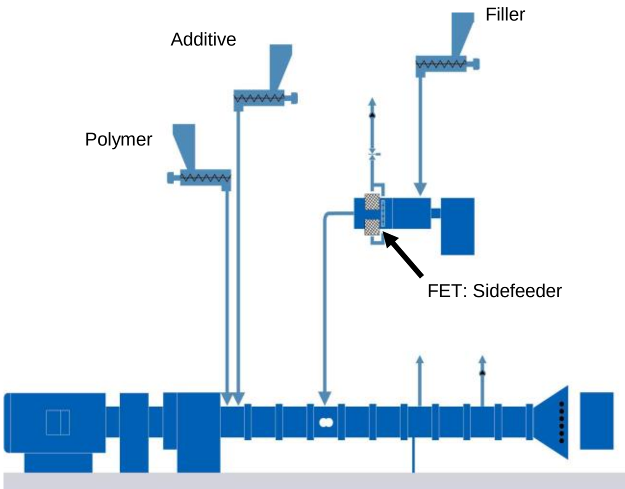

Figure 6: Set up for side-feeding feed enhancement

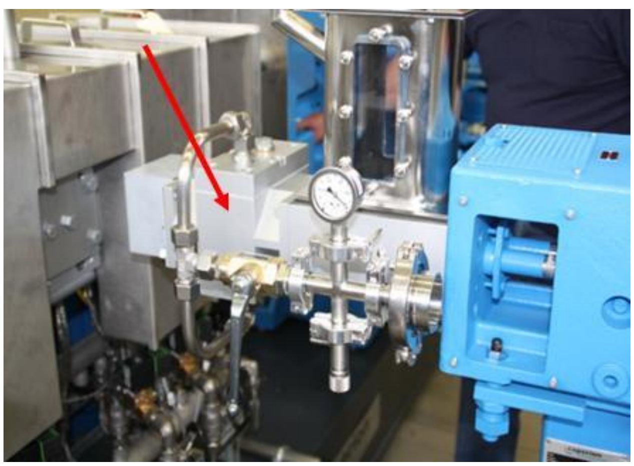

Figure 7: Side feeder modified for FET

Several sets of experiments were run on laboratory as well as production equipment to verify the productivity advantages. The first were run on a 40 mm TSE compounding unit using the same basic set up as shown in Figure 6. The base polymer was a polyamide 6. The fillers used were talc (0.25 g/cc) at 60%, HFFR powder (0.20 g/cc) at 43% and graphite (0.08 g/cc) at 50%. In each case there was a significant increase in rate as shown in Figure 8.

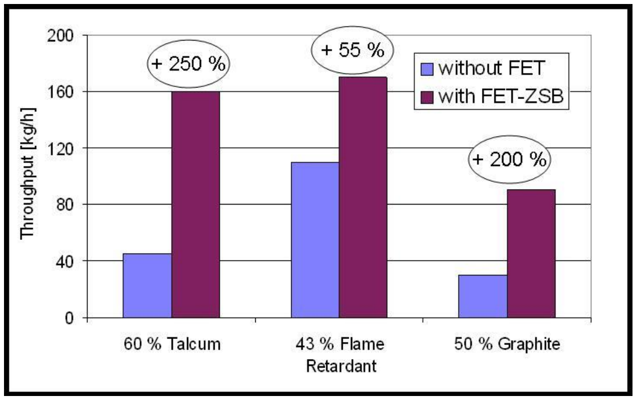

Figure 8: Rate enhancement data from 40 mm TSE laboratory line

Figure 9 shows results for a 92 mm production line used to incorporate talc. The two talc products were 1) Luzenac T1CA (particle size d_{50} of 1.6-2.1 µm) and 2) IMIFabi HM05 (0.25 g/cm^3, particle size d_{50} of 1.4 µm). While in each in instance, the rate could be increase by a significant percentage with FET, the limit for each was the talc feed intake. The absolute talc feed intake for each formulation was approximately 670 kg/hr.

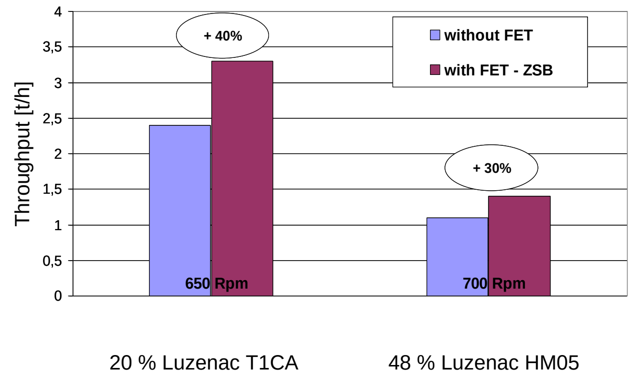

Figure 9: Rate enhancement data from 92 mm TSE production line

The previous results showed that the overall production rate could be increased by incorporating FET. However, there are other impacts of the technology. Similar to the advantages shown by Andersen [4] of using a higher torque capacity compounding unit, increasing the rate of the filled polymer line while all else remains the same, results in a lower overall energy consumption per unit of product produced. Lower unit energy translates into lower product temperature, which in turn would mean less potential for material degradation or stabilizer package consumption.

Figure 10, further illustrates this point. This data is for an 40% talc (Luzenac 1445) filled PP run on the new generation Coperion Mc[18] ZSK 45 mm twin-screw compounding extruder. Without the FET technology, the compounder can not take advantage of the higher torque capacity of the extruder. However, by implementing the FET, the system runs at full torque (~85%), the throughput has been increased more than 50% and the discharge temperature lowered significantly.

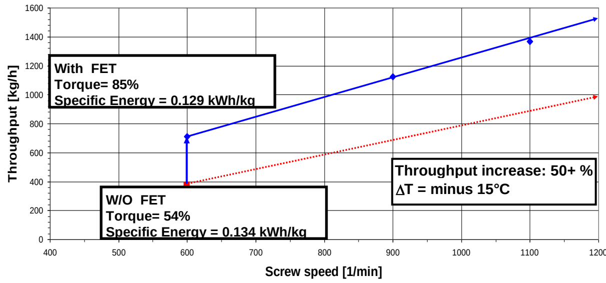

Figure 10: Impact of improved feed intake on rate and material temperature

Summary

While compounders will continue to have issues with handling low bulk density feed material, they now have an additional tool to utilize. Advantages demonstrated for feed limited processes are:

- Line production capacity can be increased
- Specific energy can be reduced for improved product stability, electrical consumption and overall line economics
- Use of finer / non compacted fillers (less expensive) is possible
- Processes can be stabilized by eliminating or reducing the impact of feed-stock particle size fluctuation
- Installation of smaller machine size possible.

Additional points to be considered are:

- Effect of FET always depends on the type of product, its particle size distribution and the particle shape
- The extruder and its auxiliaries have to be adapted to higher capacity, e.g.

  - installed motor power,
  - screw design,
  - feeding system,
  - degassing system,
  - pelletizer,
  - pellet cooling, conveying and handling system

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Key Words: Twin-screw, compounder, feed enhancement, powder filler