## SFVs to the rescue of co-rotating twin-screw extruders

Conquering feed-limitations

The external profile of intake elements plays an important role in the feed zone of a co-rotating twin-screw extruder. Typical elements used in the feed zone may be normal bi-lobed, SKE or single-lobed elements. Certain low-bulk density materials such as fine powders of talc and carbon are increasingly used as important fillers at high loading levels. When such applications are run in an extruder, there is a limit to the intake capacity after which the hopper gets flooded with material. This condition is called feed-limitation. The single deep-flighted 'V' elements (SFV) are specifically designed to improve the intake capacity of the main extruder and the side feeder, at higher speeds. With increased intake capacity, the specific energy decreases considerably, thereby providing an opportunity to utilise the full speed range of high-speed extruders, Therefore, an extruder with a small diameter of 40 mm can have the production capability of an extruder with 80 mm diameter. To know more, read on ...

The earliest co-rotating twin-screw extruders had shallow flight depths. These were designed to be run with a filled-up hopper, in the same way an i6jection-moulding machine or a single-screw extruder is run. As technology progressed and flight depths increased, it became necessary to adopt a different approach to get the material into the extruder. This approach is now popularly called starve-feeding.

In this approach, an additional feeder is used to provide a steady flow of material to the extruder. The hopper is no longer a vessel to hold materials but simply a conduit through which material enters the extruder. In many cases, it can be seen that the extruder has a large capacity for accepting such feed. If controls are not exercised, such situations can stall or break the mechanical parts and the electric-drive system.

Therefore, the limiting factor is the torque availability. While feeding polymers devoid of any other filler, the material feed rate is generally a fraction (0.05- 0.20) of the volumetric capacity of the extruder. Since there is limited material in several zones of the extruder, the extruder is considered to be 'starving'.

### Determination of starve-feed capacity

During starve-feeding, the intake capacity of the extruder depends on the screw rpm, the geometry of the intake element such as shape, free volume and lead, and the shape and bulk density of the input material.

Furthermore, the efficiency of conveying depends on the degree of fill, the type of input material (frictional coefficient and the degree of compaction), length of the intake zone and the pressure head at the end of the zone.

The formula for finding the intake capacity is:

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| Capacity = Free area x lead<br>x screw speed x bulk density<br>x conveying efficiency x degree-of-fill |

Since both 'free area' and 'lead' are related to the screw diameter (Do), it can be seen that the capacity of an extruder varies as the cube of the screw diameter (Do).

With an intake zone of 80 length requiring a compression of 20 bar at melting, while feeding talc that has low frictional coefficient (about 0.2), the conveying efficiency is generally about 20 per cent for typical intake elements.
These elements include regular conveying elements (RSEs) and SK type elements (SKEs) where the degree-of-fill is less than 0.2. With regular elements, at higher degrees-of-fill, the conveying efficiency decreases sharply. This is the reason, that in a starve-feed extruder, the hopper is never allowed to flood or fill-up. While processing low bulk density material, it can be practically seen that a flooded hopper has a lower feeding capacity than an empty one. In other words, once the intake zone is filled up (degree-of-fill = 1.0), conveying efficiency drops to less than 4 per cent.)

While feeding most other polymer material with medium frictional coefficient (about 0.4), the conveying efficiency is 30 per cent, even at higher degrees of fill up to 0.4. With calcite (frictional coefficient 0.74), the conveying efficiency is the highest (about 50 per cent) at a similar fill ratio. With these materials, increase in degree-of-fill does not decrease conveying efficiency significantly. Therefore, highest capacity is achieved when the flights are fully filled. This is the reason why a flooded hopper always creates a torque overload with most polymers.

With a deeper flighted extruder (Do/Di = 1.71) the capacity increases. This is due to increase in free area and improvements in conveying efficiency. Do is the outer diameter of the screw, and Di is the inner or root diameter of the screw. Apart from the advantage of greater intake capacity, deeper flights lead to increased efficiencies and reduced shear rates in a twin-screw extruder. With higher screw speeds, this feature is advantageous for increasing the volumetric capacity of the 'extruder, while maintaining the mixing rates.

**Evolution of extruders**

The ratio of the Do to Di is the factor that decides the free volume. The evolution of extruders based on the Do/Di ratio is outlined in Table 1.
During the initial days, machines were designed with a ratio of 1.27 and had a three-lobed profile. The need to improve the capability of an extruder has resulted in the ratio being increased all the way to 1.71. The most important aspect to be considered while selecting the ratio is the torque carrying capacity or alternatively specific torque of the extruder. A higher ratio is advantageous only if it does not compromise on the torque carrying capacity of the extruder.

The profile of the intake zone elements plays an important role in the conveying efficiency and capacity. Traditionally, profiles in the feed zones may be normal bi-lobed with leads 1.0 to 1.5 times the diameter (Figure 1).
Modified elements called SK elements (Figure 2) have 20 per cent more free volume and provide corresponding improvement in capacity.

**Need for SFV elements**

There are now many applications where fillers are added at very high percentages. Most applications with talc or extremely fine carbon are difficult to process because of severe limitations .in' intake capacity of the main feeder or the side-feeder.

While many applications are torque-limited, these specific applications become feed-limited. A new element with SFV profile can be used to substantially improve the intake capacity while starve-feeding. These elements find application especially in the deep-flighted, high-speed extruders, which can handle feed limited applications in the best possible way.

The SFV elements (Figure 3 - patent pending) are specifically designed to improve the conveying efficiency. At low screw speeds, these elements are capable of compacting the material during conveying. Increase in intake capacity of nearly 200 per cent is achievable at rpm range of 150-900.

In an experiment (Figure 4) conducted with a premix of 50 per cent talc and 50 per cent LLDPE granules, the speed versus output was found to be linear with constant torque up to 900 rpm. There was no increase In output with further increase in speed. Beyond this point, the extruder becomes torque limited instead of feed limited.

With a 40 mm extruder, a 300 per cent capacity increase has been experienced with SFV elements, running at 1100 rpm. The material is sucked in from the hopper by the partial vacuum created by the elements and compacted while conveying. With a different formulation containing 40 per cent talc, a sudden raise in starve-feeding capacity was observed at 1100 rpm, till it was limited by the torque carrying capacity of the extruder.

**Key advantages of SFV elements**

- Converts feed-limited to torque limited, utilising the extruder to a greater extent
- Improves efficiency of processing by lowering specific energy
- Side feeding of other ingredients are still possible since extruder is used in starve-feeding mode

**Applications/performance data of SFV elements**

Some fillers like $CaCO_3$, talc, carbon black, wollastonite, etc, with particle sizes ranging from 20 to 60 µm are considered to be low bulk density materials. These low bulk density materials have processing constraints with the normal bi-lobed screw elements.

The increase in output overcoming processing constraints are brought about by SFV elements. Further, the ability of the elements in the intake zone to convey powders is high.

**Case 1: $CaCO_3$ with pulverised LLDPE: Extruder Steer Omega 40**

The base polymer, LLDPE (Reliance make M26500 with melt flow index of 50) was premixed with $CaCO_3$ having particle size of 20 µm in the ratio of 80:20. The performance of SFV elements in the intake zone were compared with RSE elements, at 600 rpm. The results are shown in Figure 5.

**Case 2: Carbon black with LLDPE granules: Extruder NRII 46 SG**

The base polymer, LLDPE (72250 with MFI of 50) was compounded with carbon black N330 having particle size of 20 to 30 µm in the ratio 60:40. The performance of SFV elements in the intake zone was compared with that of RSE elements, at 450 rpm. The results are shown in Figure 6.

**Case 3: Polypropylene with talc:**
**Extruder Steer Omega 40**

The base polymer, polypropylene with MFI of 11 was premixed with talc EBT (particle size 20 µm) in the ratio 60:40. The performance of SFV elements in the intake zone was compared with that of RSE elements, at 450 rpm. The results are shown in Figure 7.

**Conclusion**

In all the trials with SFV elements in the intake zone, a substantial increase in output was observed, utilising the extruder to a greater extent, resulting in lower specific energy .•

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