OPTIMIZING SCREW CONFIGURATIONS FOR TWIN-SCREW COMPOUNDING EXTRUDERS

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optimization  noun  \äp-tə-mə-ˈzā-shən\\n
...an act, process, or methodology of making something (as a design, system, or decision) as fully perfect, functional, or effective as possible; specifically: the mathematical procedures (as finding the maximum of a function) involved in this
Optimizing screw configurations for...

- ...improved volumetric capacity – premix
- ...improved melting efficiency
- ...improved volumetric capacity – side feeding
- ...improved pumping efficiency

Summary
Production rate limitations

For most compounding applications, the maximum capacity for twin-screw compounding extruders will be limited by

- how much power they can apply or
- how much material the extruder can feed

We cannot change the volume of the extruder, but we can change the efficiency of mechanical energy input and conveying within the extruder and increase the production rate with optimized screw designs.
Optimize feeding - premix

High amount of powder (e.g. talc, CaCO$_3$) in barrel #1

Machine capacity is function of

- Screw Diameter (mm), diameter ratio ($d_o/d_i$)
- Screw speed (rpm)
- Screw design
- “Feeding” density ($kg/m^3$)
The maximum output for compounding masterbatch or highly filled polymers (talc, CaCO$_3$) is limited with premix systems by how much the extruder screws can feed in barrel #1.
After the first kneading section, the volume is reduced significantly and the machine is nearly empty. The problem is only in the main feeding area in barrel #1.
The small pitch conveying screw elements in this position are filled when feeding mostly powder in main feed barrel.
High pitch (≈2D) conveying elements from the feed zone to the kneading section reduces the fill in this part of the machine – and allows for higher capacity at same screw speed.
Optimize melting

At constant screw speed, melting efficiency decreases with increasing capacity

Kneading elements must raise temperature of solids up to melting range

Melting efficiency decreases with extruder wear

✓ Maximize screw speed
✓ Limited processing length
✓ Capacity limiting
Position of resin melting shifts downstream with increasing feed rate. As melting location moves, mixing quality/time in this section decreases.
Melt temperature prior to side feeder MUST be sufficiently high to allow for cooling effect of solids added at side feeder. Melt temperature at end of melting configuration decreases with increasing capacity.
As one example - three flight kneading elements are efficient at increasing solids temperature and accelerating the melting process.

Screw design optimization
Improved melting efficiency results in higher melt temperature prior to side feeding.
Optimize feeding – side feeder

High loadings of fine-particle fillers (e.g. talc) or fiber

Feeding capacity is function of

✓ Extruder/side feeder diameter, diameter ratio \( (d_o/d_i) \)
✓ Extruder/side feeder speed (rpm)
✓ Screw design
✓ “Feeding” density (kg/m\(^3\))
✓ “Melt quality”
Similar to feeding for premix systems, any decrease in conveying screw pitch following the side feeder creates a volumetric limit.
Screw design – side feeding

Resin must be 100% melted prior to side feeder – incomplete melting creates mixing problem. Incomplete melting also results in unstable operation of side feeder vent.
Screw design optimization

Similar to feeding for premix systems, maximum screw pitch (∼2D) should be provided from side feeder through to first mixing elements.
Optimize pumping

Insufficient backup length for required pressure

Pumping capacity is function of

- Extruder diameter, diameter ratio \( (d_o/d_i) \)
- Available pumping length \( (L/D) \)
- Extruder speed (rpm)
- Screw design
- Melt density \( (\text{kg/m}^3) \)
Screw design – die pressurization

Backup length increases with increased pressure (e.g. screen fouling). Screen lifetime becomes a function of available pumping length before vent problems occur.
Screw design – die pressurization

Devolatilization efficiency (e.g. residence time under vacuum) also decreasing with increasing backup length...
Screw design – die pressurization

Melt temperature increases significantly with increased pressure (i.e. increased backup length) due to leakage over screw flights.
Screw design optimization

Backup length is reduced dramatically with single-flight elements in pumping section. Screen lifetime now extended, melt temperature reduced and vent operation is stable.
Summary - screw design optimization

- Maximize volumetric capacity for feeding
- No decrease in conveying screw pitch
- Conveying screw elements with \( \approx 2D \) pitch
- Single-flight, other ‘special’ designs available
Summary - screw design optimization

Maximize melting efficiency

- limited processing length (L/D)
- three flight kneading elements improve efficiency
- other ‘special’ designs available
Summary - screw design optimization

Maximize side feeder efficiency

- no unmelted resin
- melt temp increased for cooling effect of solids
- proper venting of air out of barrel
Summary - screw design optimization

Maximize pumping efficiency

- minimize backup length
- single-flight, low pitch conveying elements
- reduced melt temperature, improved venting
The screw configuration can be optimized for each unit operation (feeding, melting, venting, pumping, etc.) to increase productivity, compound quality and yield.

The screw design can also be optimized to produce a broad spectrum of compounds (minimizing changeover) – at the expense of capacity.

Alternate types of modular co-rotating extruder element designs have been developed over the recent years to enhance the performance of high speed, high torque machinery.

Summary
Thank You!