Maximizing Productivity for Twin-Screw Compounding

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Presentation outline

✓ Increase capacity
  - Optimized screw designs for feeding limitation
  - High torque and high speed compounding

✓ Improve quality
  - How extruder wear affects compound quality

✓ Maximize profitability
  - Highest production rate
  - Achieve and maintain compound quality
  - Best machine reliability
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 for conveying material within the extruder and increase the production rate with optimized screw designs.
Increasing capacity - premix

When main feed port is full

High amount of powder (e.g. Talc, CaCO$_3$)

Machine capacity is function of

✓ Screw Diameter (mm)
✓ Screw speed (rpm)
✓ Screw design
✓ Bulk 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.
Feed limitation - premix

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.
These powder-filled screw elements cannot convey more material – so the capacity of feeding is limited → here
Feed limit - premix
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To increase capacity – we must increase the pitch of conveying elements in this area.
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Maximizing capacity - premix

The screw design must use the highest pitch conveying elements from the main feed area all the way through to the kneading elements.

Special design feeding screws can further increase capacity for formulations with very low bulk density, less than 0.1 (e.g. silica).

This approach can increase productivity for existing machines using premix feeding...

The highest capacity is achieved using downstream feeding with side feeders...
Increase capacity – side feeding
Feed limitation – side feeding

When side feeder is full

High amount of powder (e.g. Talc, CaCO$_3$)

Feeding capacity is function of

✓ Extruder/Side Feeder Screw Diam (mm)
✓ Extruder/Side Feeder Screw speed (rpm)
✓ Screw design
✓ Bulk density (kg/m$^3$)
✓ “Melt quality”
Limitations for downstream feeding of fine-particle talc:

1. Polymer melting
2. Polymer melt temperature/viscosity at side feeder
3. Venting/degassing of air from barrel
If polymer is not 100% molten at side feeder:
1. Downstream mixing of talc results in poor dispersion
2. Atmospheric vent does not work (material comes out)

MUST VISUALLY CONFIRM 100% MELTED POLYMER AT SIDE FEEDER (there must be NO un-melted resin at this point)
Fillers (talc, CaCO3, pigments, etc.) added here through a side feeder will **not** disperse into solid (unmelted polymer) pellets. The screw design for resin melting is critical when using side feeders.
If melt temperature is not high enough at side feeder:
1. Adding 30% talc (25°C) at side feeder reduces polymer melt temperature **approx. 30°C** – this increases melt viscosity dramatically
2. If melt temperature is too low – polymer becomes solid again at side feeder!
3. Higher melt viscosity = more difficult to mix with talc
Problem: polymer melt temperature

If melt temperature is not high enough at side feeder, polymer will become solid when 30% talc is added (melt temperature decreases >30°C)
Problem: venting/degassing air

Conveying elements in side feed area must be >1.5D pitch:

1. Low pitch conveying element limits volume of talc conveying (e.g. volume-limit, *same problem as premix feed*)

2. Highest screw pitch provides lowest degree-of-fill and optimum venting of air through screw
Solution: optimized screw design

Increased polymer melting efficiency:
1. Elimination of unmolten polymer at side feeder
2. Increased melt temperature at side feeder = no solidification
3. Maximum conveying efficiency = low degree-of-fill
“Stronger” screw design for melting polymer – increases melt temperature so that cooling effect of feeding talc does not cause polymer to become solid.
Solution: optimized screw design

Improved volumetric capacity:
1. 2D pitch conveying elements at vents and side feeder
2. Maximum screw pitch (2D recommended)
Solution: optimized screw design

Low degree-of-fill at side feeder and vents – allows air to move through extruder barrel easier, keeps talc from backing-up in screw

2D pitch conveying elements in side feed and vents
Proposal for (>70% filler) – requires multiple side feeders and multiple atmospheric vents – to maximize the flow of air out of the extruder barrel (L/D for this line is 48). Additional atmospheric vent before side feeder increases talc feeding capacity combined with 2D pitch conveying elements.

Talc is split into two downstream side feeders for loadings >40%. The limitation for downstream talc feeding is cooling effect on molten polymer.
Maximum capacity – side feeding

- Modification of screw design to provide 2D screw pitch throughout the side feed/vent areas will provide increased capacity for talc and glass feeding.

- Modification of the melting section of screw designs will also improve talc feeding and increase capacity (you should visually confirm presence of any unmelted polymer at side feeder with current screw design).

- Machine configuration includes multiple vent openings (upstream and downstream of side feeders) and these types of screw configurations designed to optimize fine-particle talc feeding and maximize machine capacity.
Maximize capacity – torque limit

The production capacity can be limited by torque (motor power) when compounding…

✓ polymers with high melt viscosity
✓ fillers with high bulk density (e.g. TiO$_2$)
✓ with side feeders
✓ temperature-sensitive additives (e.g. FR)

*In these cases, extruders with high specific torque (Nm/cm$^3$) will provide more capacity*
Specific torque (torque density)

The installed power (kW) for a given size extruder is a function of

- ✓ screw diameter
- ✓ screw speed (higher speed = higher kW)
- ✓ gearbox technology
- ✓ screw shaft metallurgy

*When compounding low-bulk density fillers or premix feeding, high screw speed (>600 rpm) can also provide increased capacity*
Available power vs specific torque

Maximum power is available only at maximum screw speed

[specific torque = 4.8 Nm/cm³]
Available power vs operating torque

Cannot operate machine at 100% torque – how much power is available at 85% torque?

Maximum Motor Amps

85% Max Amps

600 rpm

Screw speed

[specific torque = 4.8 Nm/cm³]

TSE65

Power (kW)

90

76.5

85% Max Torque

90% Max Amps

250 rpm

Maximum Motor Amps

Screw speed

85% Max Torque

600 rpm

Screw speed

[specific torque = 4.8 Nm/cm³]
Maximum capacity vs specific energy

Maximum capacity for torque-limit is based on the specific energy requirement of the compound – typical specific energy values are between 0.15 and 0.25 kWh/kg (difference is based on polymer type and viscosity, filler type and percentage, etc.)
Maximum production rate - design capacity

Maximum capacity at 0.25 kWh/kg = \( \frac{76.5\text{kW}}{0.15\text{kWh/kg}} \) = 306 kg/hr

Maximum capacity at 0.15 kWh/kg = \( \frac{76.5\text{kW}}{0.25\text{kWh/kg}} \) = 510 kg/hr
Increased torque density

Power (kW)

160

TSE65 PLUS

[specific torque = 8.5 Nm/cm³]

Increased torque density (8.5 Nm/cm³) provides 77% more power

Maximum Motor Amperage = 100

Screw speed →

600 rpm
Available power vs operating torque

Power (kW) | TSE65 PLUS |
---|---|
160 | 136 |

[specific torque = 8.5 Nm/cm³]

Cannot operate machine at 100% torque – how much power is available at 85% torque?

Screw speed → 600 rpm

85% Max Amps

Maximum Motor Amps

160% Torque

Cannot operate machine at 100% torque – how much power is available at 85% torque?
Maximum capacity for torque-limit is based on the specific energy requirement of the compound – typical specific energy values are between 0.15 and 0.25 kWh/kg (difference is based on polymer type and viscosity, filler type and percentage, etc.)
TSE65 PLUS

Power (kW)

160
136

Specific torque = 8.5 Nm/cm³

Maximum capacity at 0.25 kWh/kg = (136kW ÷ 0.15kWh/kg) = 544 kg/hr

Maximum capacity at 0.15 kWh/kg = (136kW ÷ 0.25kWh/kg) = 906 kg/hr

Max Motor Amps

85% Max Amps

Screw speed → 600 rpm
Capacity increase with high torque machine

Power (kW)
- RXT65: 315
- TSE65 PLUS: 160
- TSE65: 90

Screw speed
- 600 rpm
- 1000 rpm

Specific torque:
- RXT65: 11.0 Nm/cm³
- TSE65 PLUS: 8.5 Nm/cm³
- TSE65: 4.8 Nm/cm³
Capacity increase with high speed machine

- **TSE65 PLUS**
  - Power (kW): 325
  - Screw speed: 1000 rpm
  - Specific torque: 8.5 Nm/cm³

- **RXT65**
  - Power (kW): 160
  - Screw speed: 1000 rpm
  - Specific torque: 11.0 Nm/cm³

- **TSE65**
  - Power (kW): 160
  - Screw speed: 600 rpm
  - Specific torque: 4.8 Nm/cm³

- **TSE65**
  - Power (kW): 90
  - Screw speed: 600 rpm
  - Specific torque: 8.5 Nm/cm³
Increased torque density (11.0 Nm/cm³) and higher screw speed range (up to 1000 rpm) provides 4X more power.
Capacity increase with high speed machine

Power (kW) 325

RXT65

80% Max Screw Speed

[specific torque = 11.0 Nm/cm³]

Available power at 80% maximum screw speed (e.g. compound quality limited by melt temperature)
Capacity increase with high speed machine

Available power at 80% maximum screw speed and 85% maximum motor amperage

- Power (kW) 325
- RXT65
- 80% Max Screw Speed
- 800 rpm
- 1000 rpm
- [specific torque = 11.0 Nm/cm³]
- 85% Max Amps
Maximum capacity at 80% maximum screw speed and 85% maximum motor amperage = 884 - 1473 kg/hr (based on specific energy values 0.15 to 0.25 kWh/kg)... RXT series high-speed and high-torque extruders can deliver 2.8X capacity of “standard” torque machines.
Maximizing Quality

High-quality compound is produced at maximum capacity with proper extruder configuration, screw design and operating conditions.

Compound quality and/or capacity will decrease over time as screws and barrels wear. This situation is unavoidable when compounding abrasive fillers (CaCO$_3$, TiO$_2$, glass fibers, etc.).

Maximizing profitability requires maintaining both quality and capacity over time...
Feeding abrasive fillers into the main feed port (TiO$_2$, CaCO$_3$, talc, etc.) provides good dispersion but reduces the service life of screws/barrels.
As the flights of conveying elements are worn, conveying efficiency is reduced. As wear progresses, feed-limitation can be observed (i.e. backup into main feed port) and production rate must be reduced.
Screw speed can be increased to compensate for reduced conveying efficiency – for a while. The rate of wear of conveying elements is accelerated with higher screw speed.
Abrasive wear: quality and productivity
The first kneading elements are worn, melting and mixing efficiency is reduced. As wear progresses, melting of resin(s), dispersion of filler and mixing of additive(s) moves to downstream kneading elements.
As wear progresses, deterioration of physical properties results from decreased melting and mixing. Unmelted resin appears at side feeder, downstream mixing of fillers is affected (venting problem at side feeder).
Screw speed can be increased to compensate for reduced efficiency of kneading elements – for a while. The rate of wear of kneading elements is accelerated with higher screw speed.
Abrasive wear: quality and productivity

As first kneading elements wear, melting is delayed – note mixing cannot start until melting is completed!
Abrasive wear: quality and productivity

Wear in melting section can result in unmelted resin at side feeder – this problem produces unacceptable physical properties.
Feeding abrasive fillers downstream using side feeder minimizes wear (compared to feeding in main feed port); first kneading element(s) exposed to glass fiber, talc, CaCO$_3$, etc. experiences highest mechanical stress.
Abrasive wear: quality and productivity

Similar to wear of kneading elements in the melting section – mixing deteriorates as the kneading elements wear and is observed as decreased physical properties. Filler appears in vacuum vent or on screens.
Abrasive wear: quality and productivity

Similar to wear of conveying elements in the melting section – conveying efficiency also decreases as these conveying elements wear and is observed as a feeding limit at the side feeder (backup); production rate must be reduced.
Screw speed can be increased to compensate for reduced conveying and/or mixing efficiency – for a while. The rate of wear of conveying and kneading elements is accelerated with higher screw speed.
Where is the wear?

Vacuum Zone

If clearances are enlarged (from abrasive wear) within the restriction element used to create a melt seal for vacuum, sustainable vacuum level is reduced.
Where is the wear?

Vacuum Zone

Diagnosing a worn melt seal is easy – polymer is pulled from the vacuum port only under vacuum; at atmospheric pressure, polymer remains within the extruder screws.
Where is the wear?

Vacuum Zone

Screw speed can be decreased to compensate for worn restriction elements to increase pressure drop – for a while. Note that melting and mixing are decreased at reduced screw speed.
Where is the wear?

As the flights of conveying elements are worn in the pumping section, conveying efficiency is reduced and the backup length required to develop pressure increases to upstream (i.e. unworn) conveying elements.
Where is the wear?

Screw speed can be increased to compensate for reduced pumping – for a while. The rate of wear of conveying elements is accelerated with higher screw speed.
As wear progresses in the pumping section, melt eventually backs-up into vacuum vent.
When vacuum vent has problems, both compound quality AND capacity are affected.
Minimizing abrasive wear

How much wear is OK…?

The answer is not straightforward – depends on product sensitivity with respect to dispersion; some compounds cannot be produced when even small amounts of wear are observed, while other materials can be produced with severe wear on screws and barrels…

You need to wear down the machine until you produce ‘unacceptable’ quality – at this point, you can measure screws and barrels and understand your own replacement frequency.
Minimizing abrasive wear

Identify an appropriate metallurgical solution

Presentation describes wear of screw components – barrel wear *always* accompanies screw wear, usually at a slower rate.

Reducing wear rate implies identifying suitable chemistry for materials of construction and fabrication method:

- *Hot Isostatic Pressing (HIP)*
- *Powder Metallurgy (PM)*
- *Barrel liner, element crest welding, etc…*
Minimizing production cost-per-kg

Selection of proper wear materials for screws and barrels will reduce compound cost per kilogram

![Wear and Corrosion Comparison Chart]

- Nitralloy (Nitrided)
- CPM 9V
- CPM 10V
- 10V-12
- CPM 15V
- Cast Iron
- D2
- 420V
- 440C
- CS 460
- Inconel 625+
- Wexco 555
- Wexco 777
- 17-4 PH

Material

Selection of proper wear materials for screws and barrels will reduce compound cost per kilogram.
Maximizing profits

Ruiya Extrusion together with Century Extrusion have the tools to improve your profitability:

✓ Screw design expertise
✓ Cost-effective TSE series extruders
✓ High-speed/high-torque extruders
  - PLUS series
  - APEX/RXT series
✓ Metallurgical solutions for high-wear

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