Twin Screw Extrusion Developments for Processing Color Masterbatches and Compounds

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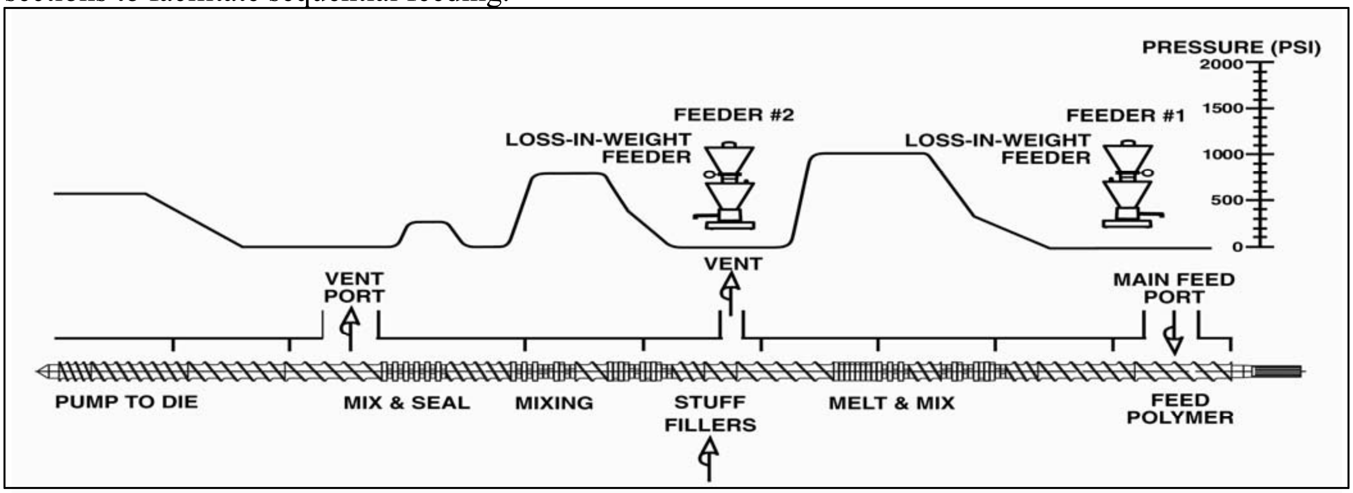
High speed, energy input (HSEI) co-rotating intermeshing twin screw extruders (TSE's) are the manufacturing methodology of choice in the plastic's industry to continuously mix polymers, pigments and additives for a wide range of masterbatches. The final product is typically a pellet to facilitate accurate/consistent feeding into an injection molding machine or single screw extruder.

HSEI twin screw extruders utilize segmented screws that are assembled on high torque splined shafts. Barrels are also modular and utilize liquid cooling. The motor inputs energy into the process via rotating screws that impart shear into the materials being processed. Segmented screws/barrels, in combination with the controlled pumping and wiping characteristics of the co-rotating, self wiping screws, allows screw/barrel geometries to be matched to the process tasks. Solids conveying and melting occurs in the first part of the process section. Screw elements for mixing and devolatilization are then utilized as dictated by the process. Discharge elements finally build and stabilize pressure to the die or front-end device.

HSEI Co-rotating intermeshing twin screw extruder screw set

HSEI twin screw extruders are starve fed, with the output rate determined by the feeder(s), which meter pellets, liquids, powders and fibers into the process section. The extruder screw RPM is independent from the feed rate and is used to optimize compounding efficiencies. Because the pressure gradient is controlled, and zero for much of the process, materials are easily introduced into downstream barrel sections to facilitate sequential feeding.

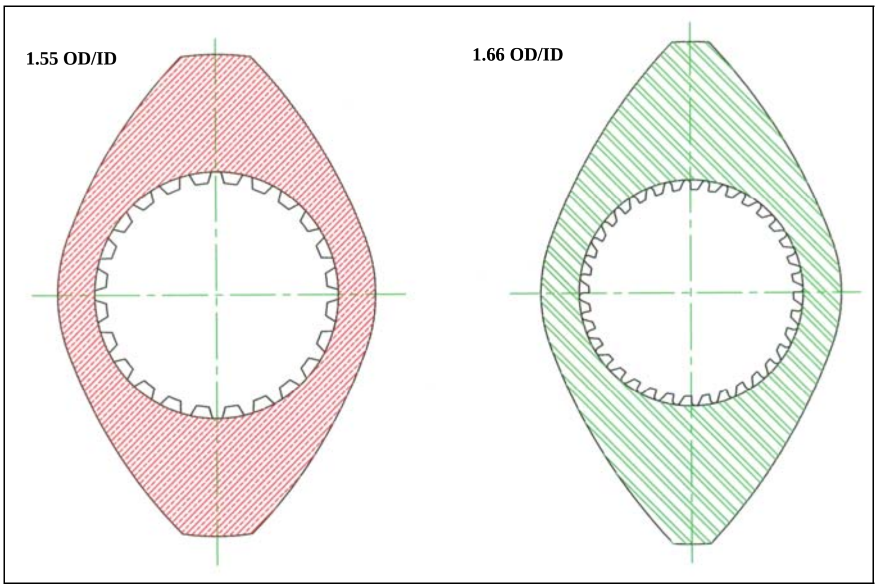


Pressure gradient in a HSEI twin screw extruder

Advancements for Increased Free Volume, Higher Torque and Better Cooling

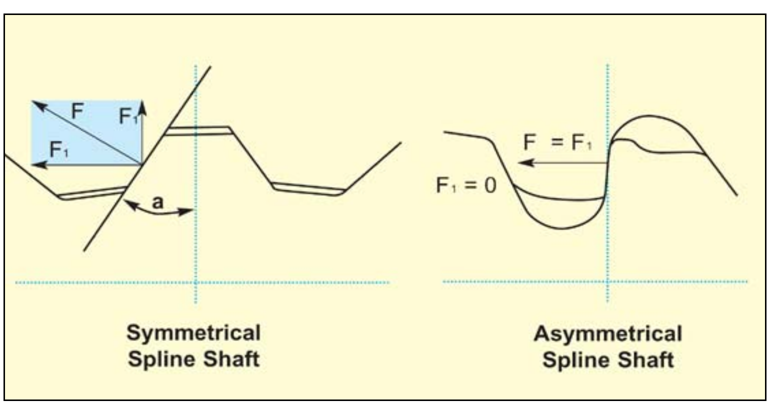
Free volume is an important design parameter for any HSEI twin screw extruder, and is directly related to the OD/ID ratio. The OD/ID ratio is defined by dividing the outside diameter (OD) by the inside diameter (ID) of each screw. The torque limiting factor for a HSEI twin screw extruder has historically been the cross-sectional area of the screw shaft. Deeper screw flights result in more free volume, but with less torque, since a smaller diameter screw shaft is mandated.

Based on the use of a symmetrical splined shaft, a 1.55 OD/ID ratio has been deemed to offer the best balance of torque and volume. In 2004 a HSEI twin screw extruder series was introduced with a 1.66/1 OD/ID ratio that increased free volume by approximately 30% without sacrificing torque. In Leistritz nomenclature its' HP series has a 1.55/1 OD/ID, and the MAXX series a 1.66/1 OD/ID ratio.



End view HP and MAXX screw element geometries

The MAXX series utilizes a patented asymmetrical splined shaft which isolates the tangential force vector and improves the power transmission efficiency of the screw shaft, allowing a smaller diameter shaft to transmit higher torque. After introduction, it became evident that with asymmetrical splined shafts the torque limiting factor became the gearbox. In 2007 a new generation of gearboxes was introduced that increased the available torque of the HSEI twin screw extruder by an additional 30%.



Comparison one-tooth of symmetrical and asymmetrical screw shaft geometries

Shear forces result in mixing, which is the primary function of most HSEI twin screw extruders. Shear rate describes the velocity gradient between two surfaces moving at different speeds. For a HSEI twin screw extruder this is a function of screw outside diameter, screw speed and overflight gap. When comparing 1.55/1 versus 1.66/1 OD/ID ratios the following formula for peak shear is relevant:

$$\text{Peak shear rate} = (\pi * D * n)/(h * 60)$$

Where D is the screw diameter, n is the screw speed in RPM, and h is the overflight clearance. So to compare the ZSE-27 HP (with a screw diameter of 27mm and overflight gap of .1 mm) versus ZSE-27 MAXX (with a screw diameter of 28.3mm and overflight gap of .1 mm) at 600 RPM the following applies.

$$\text{ZSE-27 HP Peak shear rate} = (\pi * 27 * 600)/(.1 * 60) = 8478 \text{ sec.}^{-1}$$

$$\text{ZSE-27 MAXX Peak shear rate} = (\pi * 28.3 * 600)/(.1 * 60) = 8886 \text{ sec.}^{-1}$$

The higher tip speed inherent with a larger diameter screw diameter for the MAXX design results in a higher peak shear value. It should be noted that this formula is merely a benchmark, as it does not take into account the extensional shear effects, directional flow changes, and pressure fields that are also components of dispersive mixing.

HSEI twin screw extruder barrel sections utilize longitudinal internal cooling bores to maintain temperature set-points. Liquid enters/exits the bores by transverse “header” bores drilled through the flanges. State-of-the art barrel designs now utilize (2) inlet ports and (2) outlet ports for each barrel section which facilitates increased coolant flow and cooling efficiencies. Previous barrel designs utilized a single inlet/outlet for each barrel.

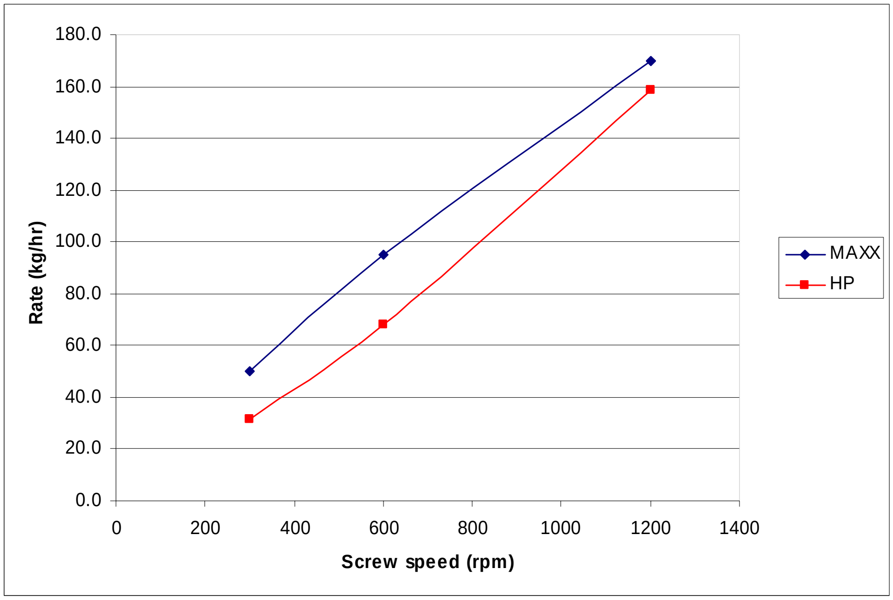
Barrel temperatures are used to manage the viscosity of the melt, which impacts the mixing quality. The magnitude of the shear stress that the materials experience, which results in dispersive mixing, is a function of the shear rate and viscosity, and is reflected by this formula:

$$\text{Shear stress} = \text{Viscosity } (E_C) \text{ x shear rate}$$

Cooling is often used to strategically raise the viscosity of the melt in combination with mixing elements that accentuate extensional and planar shear effects for dispersive mixing applications, as is required for many pigmented formulations.

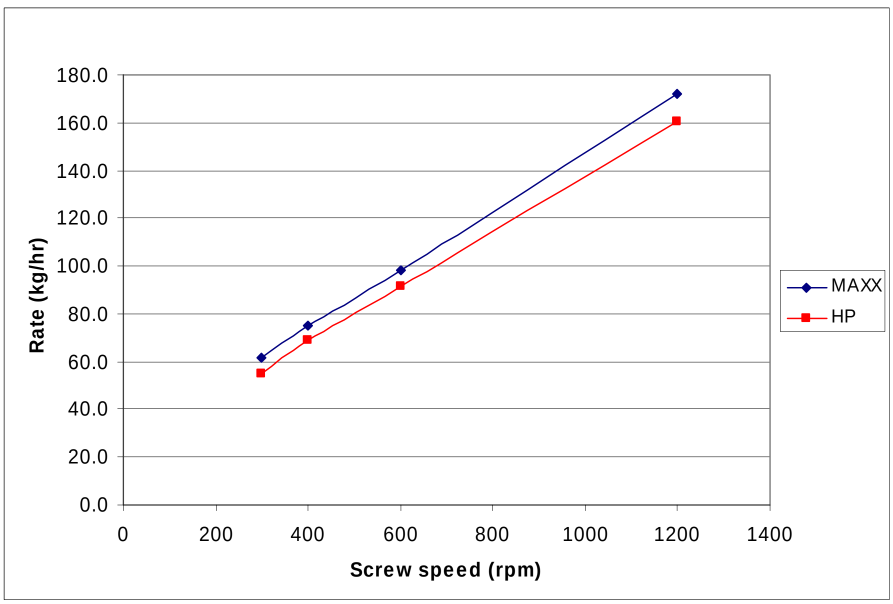
Experimental data has been generated comparing the HP to the MAXX series. HP and MAXX process sections are interchangeable and can be mated to the same gearbox/motor. Initial tests were performed with neat resins with ZSE-27 HP and MAXX models with a 40/1 L/D process section and 50 HP motor:

LDPE Powder: LDPE powder feedstock with a 12 MFI was processed on ZSE-27 HP (27 mm dia. screws) and MAXX (28.3 mm dia. screws) models. The 1.66/1 OD/ID ratio made it possible to feed more material to the extruder before encountering feed limitation. In each instance, the rate limiting factor was the volumetric feed capacity of the feed throat. The process was not torque limited. Melt temperature was also significantly lower.



Rate Comparison: MAXX vs HP for 12MFI PE Powder

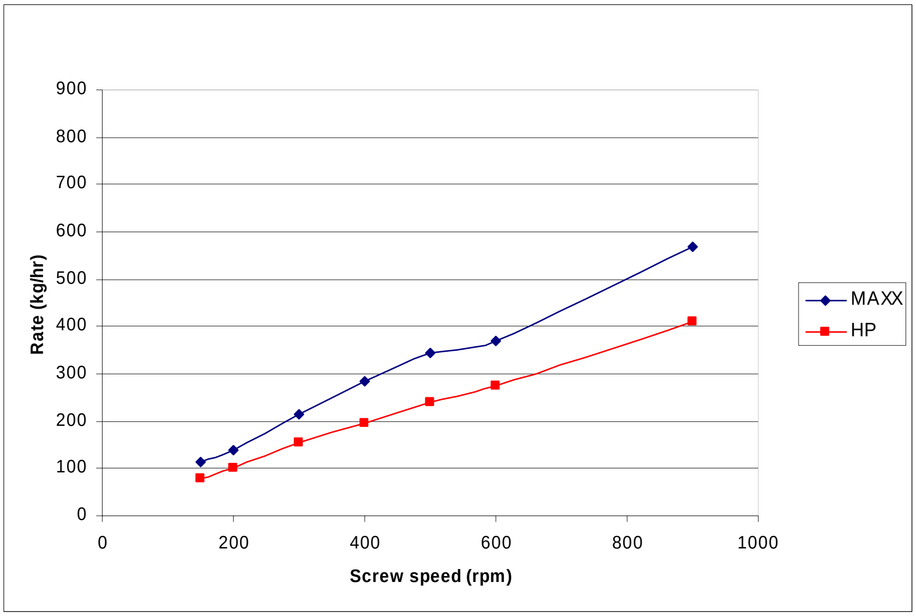
PLA pellets: PLA (Natureworks 2002D) processed at approximately 10% higher rates with lower melt temperatures on the ZSE-27 MAXX as compared to the HP. All samples were torque limited, not feed limited. It is probable that the melting mechanism inherent with the MAXX design allowed the slightly higher throughputs with a lower melt temperature.



Rate Comparison: MAXX vs HP for PLA

Subsequent tests were performed comparing the ZSE-27&50 HP and ZSE-27&50 MAXX (with increased torque) models with the following results:

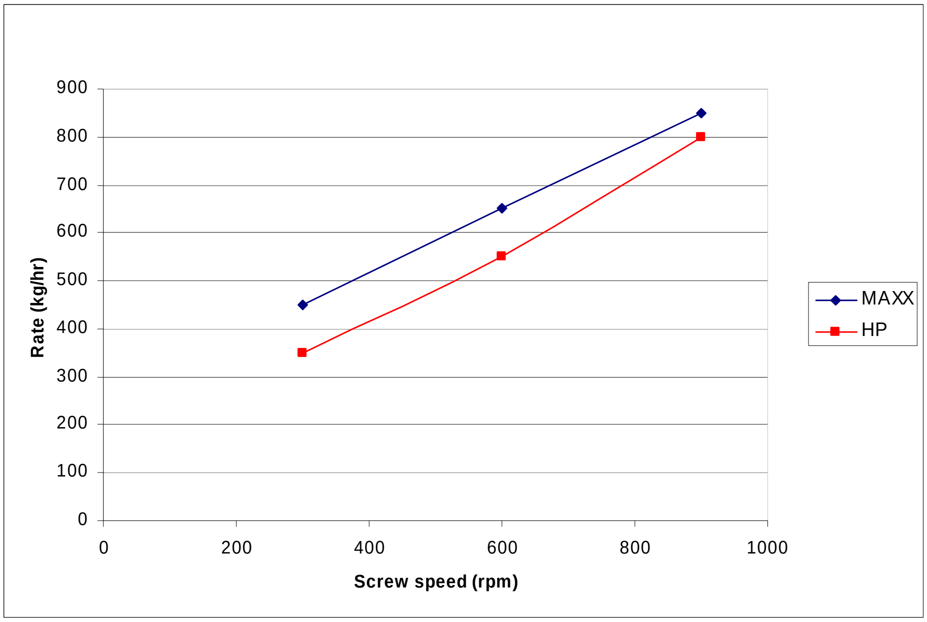
Fractional melt HDPE with carbon black masterbatch: Both pellet feed streams were metered into the main feed throat of ZSE-50 HP (50 mm dia. screws) and ZSE-50 MAXX (51.2 mm dia. screws) models via loss-in-weight feeders. The ZSE-50 MAXX was able to process approximately 40% more throughput rates with equal or better mechanical properties. All rates were torque limited.



Rate Comparison: HDPE with Carbon Black Masterbatch

Pre-mix versus split feed pearlescent pigment masterbatch: A formulation of 75% PP, 20% pearlescent pigment and 5% wax was pre-mixed and fed into the main feed throat of a ZSE-27 HP. The same formulation was also processed on the ZSE-27 MAXX, except the ingredients were metered separately, and the pearlescent pigment was fed downstream via a side stuffer. Equivalent throughputs rates were processed and product quality was compared. It was determined the quality of the masterbatch produced on the ZSE-27 MAXX was significantly better due to less destructuring of the pearlescent pigments during processing.

Split feed highly filled masterbatch: A formulation of 15% PP/additive and 85% $CaCO^3$ was processed on ZSE-50 HP and MAXX models. The PP/additive was metered into the main feed throat. The $CaCO^3$ was introduced sequentially into the main feed throat and via two (2) downstream side stuffers. The ZSE-50 MAXX processed this formulation with approximately 10 to 30% higher throughput rates. All rates were volume limited.



Rate Comparison: PP with 85% $CaCO^3$

Summary

It is apparent that the HSEI twin screw extrusion advancements offer manufacturing opportunities for any process that is volume, torque or temperature limited. It is important for processors to be aware of and to implement the latest HSEI twin screw extrusion technologies, as appropriate, into their operations to optimize efficiencies and make a better product.

References:

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Todd, David B. Plastics Compounding: Equipment & Processing. Hanser/Gardner, 1998

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