MANAGING MELT TEMPERATURE IN A TWIN SCREW EXTRUDER

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Abstract

The high speed, co-rotating, intermeshing twin screw extruder (TSE) is the most prevalent device for continuous mixing of polymers (i.e. PE and PP) with additives and fillers. Exotic formulations that utilize atypical active ingredients are also processed on this device. Materials exposed to high shear and temperatures will degrade. Most products benefit by strategically managing how shear (and energy) is imparted into the materials being processed and measured by the resulting melt temperature.

Various factors are considered to manage and control the melt temperature, including operating conditions and screw design. In this paper, emphasis will be given to OD/ID ratio, and the melting zone in the screws.

Introduction

Twin screw extruder theory and design basics:

TSEs 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. Feeders meter material into the TSE process section and the screws rpm is independent and set to optimize processing efficiencies. Segmented screws/barrels, in combination with the controlled pumping and wiping characteristics of the co-rotating 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. Discharge elements then build and stabilize pressure to a die or front-end device.

The free volume in the process section is 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. Deeper screw flights result in more free volume, but with less torque, since a smaller diameter screw shaft is mandated.

Twin screw extruder advancements for increased free volume and higher torque:

Asymmetrical splined shaft designs offer improved power transmission efficiency so that a smaller diameter shaft can transmit higher torque than before. This is accomplished by isolating the tangential force vector transmitted from the shafts to the screws from the motor. The combination of both higher torque and larger OD/ID ratio has proven beneficial for many processes.

In Leistritz nomenclature the HP series has a 1.55/1 OD/ID ratio and uses an symmetrical splined shaft design, and the MAXX series uses a 1.66/1 OD/ID ratio with an asymmetrical splined shaft. Increasing the OD/ID ratio increases the free volume by approximately 20% with the same, or higher, torque rating. The image below indicates a 1.55/1 OD/ID as compared to a 1.66/1 OD/ID ratio, as well as symmetrical and asymmetrical tooth designs.

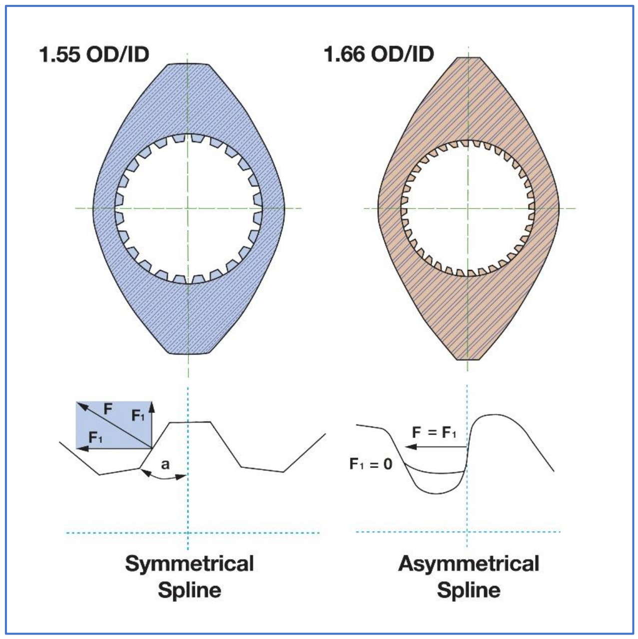

Figure 1: End view HP and MAXX screw element geometries.

Experimental Data

Case Study #1: Comparing twin screw extruders with 1.55/1 and 1.66/1 OD/ID ratios:

Previous experimental data was generated comparing 1.5/1 OD/ID and 1.66/1 OD/ID model TSE's. Process sections were interchangeable and mated to the same gearbox. Initial tests were performed with a neat resin with a 40/1 L/D process section and 40 HP motor:

LDPE powder feedstock with a 12 MFI was processed on ZSE-27 HP (27 mm dia. screws, 1.5/1 OD/ID ratio) and ZSE-27 MAXX (28.3 mm dia. screws, 1.66/1 OD/ID ratio) models. In each instance, the rate limiting factor was the volumetric feed capacity. The 1.66/1 OD/ID ratio made it possible to feed more material to the feed throat before encountering feed limitation. The increase in achievable feed rate was comparable to the increased free volume associated. At elevated screw rpms (greater than 800) the percentage increase was not as pronounced, as the higher screw tip velocity seemingly had a "propeller" effect that somewhat inhibited feeding.

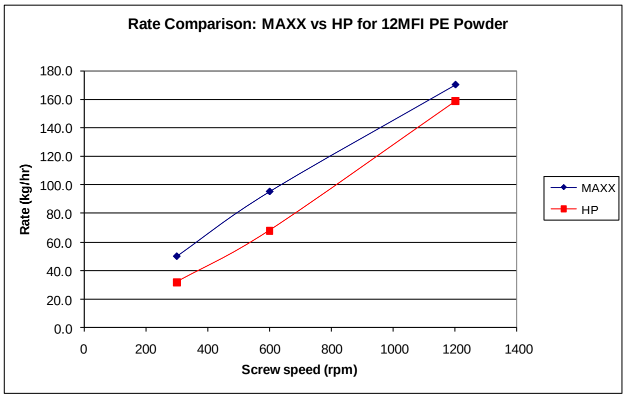

Figure 2: Rate comparison: MAXX vs HP for 12MFI PE Powder.

The corresponding melt temperatures were lower for the 1.66/1 OD/ID ratio (at the higher rates) due to a lower specific energy input (kW) into each kg being processed and the gentler mixing effect associated with deep-flighted 1.66/1 OD/ID screw geometry.

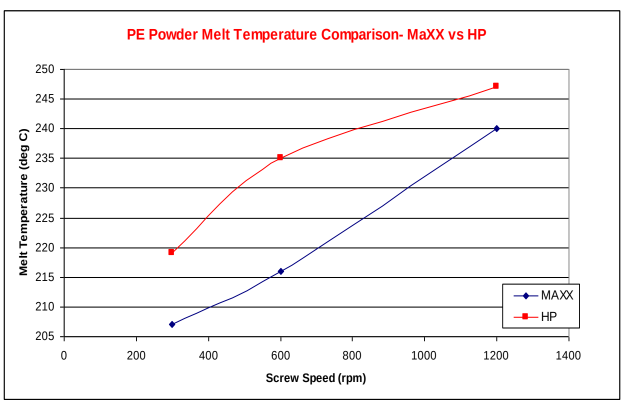

Figure 3: Melt temperature comparison: MAXX vs HP for 12 MFI PE powder.

Case Study #2: Comparing different melting zone screw configurations:

A series of experiments were performed on a ZSE-27 MAXX (28.3 mm dia. screws and 1.66 OD/ID ratio) to compare the resulting melt temperature for different melting zone screw configurations for a 2 MFI PP. An "aggressive" melting zone with melting completed by barrel position 3 (12 L/D) was compared to an "extended" melting zone, where melting was completed by barrel position 4 (16 L/D). A single kneading block set was specified after melting in an attempt to isolate and compare the different melting zone configurations, and the resulting melt temperature. A low-pressure discharge die was used to minimize the effects of pressure on melt temperature. Both flush and immersion melt temperature probes were utilized in the experiments. Various rates and screw rpms tests were performed and compared.

The aggressive melt zone design utilizes neutral/wide disk kneading block elements and a reverse element to achiee a full melt of the polymer by barrel 3. The goal of the aggressive melt zone might be to specify a shorter L/D, or to free up space in latter parts of the process for additional unit operations, i.e. injection, mixing or devolatiliation.

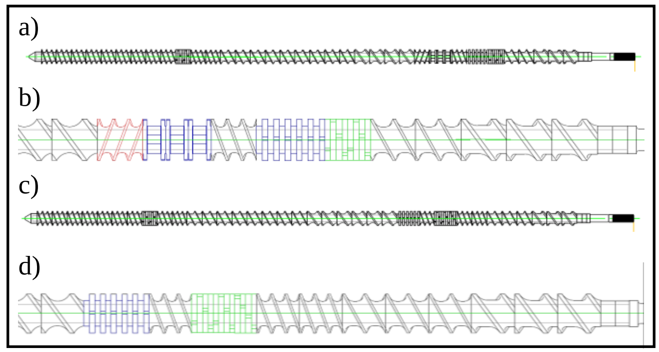

Figure 4: a) Aggressive melting zone screw design b) Aggressive melting zone closeup c) Extended melting zone Screw design d) Extended melting zone closeup.

In comparison, the extended screw design utilizes narrow disk kneading block elements with less intensive shear stress input into the polymer, which results in a more gradual melting of the polymer. The goal of the extended melt zone is to reduce the melt temperature and shear stress exposure for the materials being processed.

Table 1: Temperature Setpoints and Process Section Setup.

Temperature Setpoints (°C)		
Zone 0	Main Feed	COLD
Zone 1	Solid	255
Zone 2	Solid	266
Zone 3	Solid	266
Zone 4	Solid	255
Zone 5	Solid	244
Zone 6	Solid	244
Zone 7	Solid	233
Zone 8	Vent (atm.)	233
Zone 9	Solid	233
Zone 10	Swing Gate	233

All experimental data was collected on the ZSE 27 MAXX (28.3 mm dia. screws, 1.66/1 OD/ID). A PE pellet resin with a melt flow of 2 g/10 min. was used. A temperature profile was somewhat optimized and 400, 600, and 1000 screw rpms were tested. The data in the melt temperature graphs below (unless otherwise noted) were obtained with the handheld immersion probe.

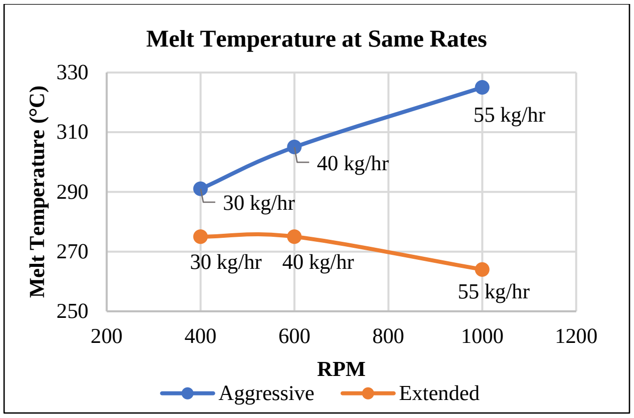

Figure 5: Comparing the melt temperature at the same rates.

In each instance, the melt temperature with the aggressive design was much higher then the extended design. The decrease in melt temperature above 40 kg/hr on the extended design might be due to a lower degree of fill in the channels at high rpm and low rates resulting in a higher cooling efficiency in barrel zones 5-9.

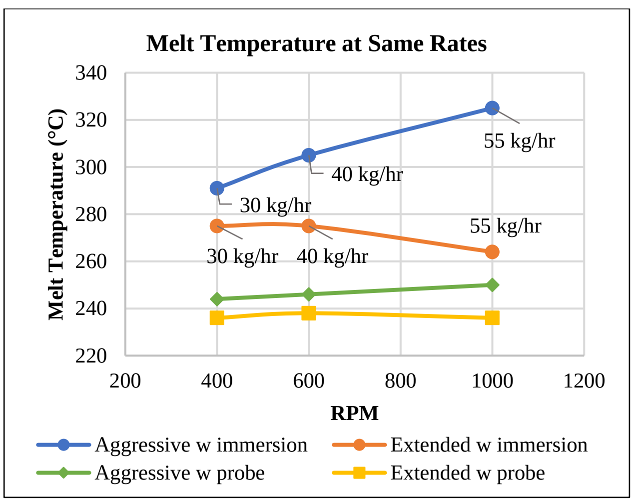

Figure 6: Comparing the melt temperature at same rates with the flush and immersion melt probes.

When analyzing the data, it was important to note that the immersion probe measured significantly higher than the flush melt probe, which did not change drastically due to rate or rpm. It seems that because the melt probe was not fully immersed into the polymer melt, the melt probe reading is highly influenced by the metal adapter setpoint.

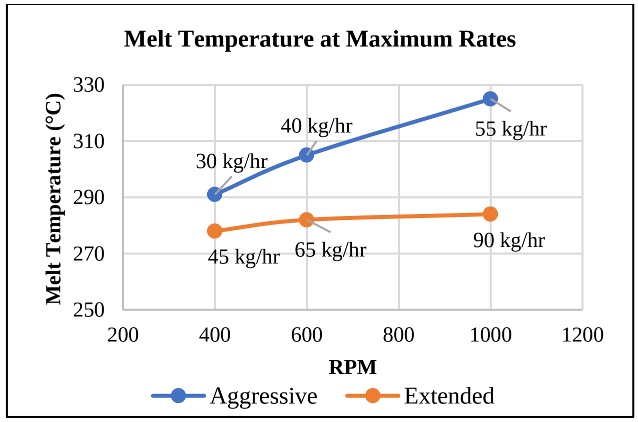

Figure 7: Comparing melt temperature at maximum rates.

The rate was also maximized with both melt designs at a target of approximately 85% operating torque. The extended screw design resulted in higher rates than the aggressive screw design. With both screws operating at 85% torque and maximum rates, the melt temperature of the aggressive screw design was still much higher than the extended.

Comparing the two melting zones, one aggressive and one extended, it was shown that the aggressive melting zone caused a significant temperature rise and lower attainable rates when compared to the extended melting zone. The higher temperatures inherent with the aggressive screw design indicated significant degradation, seen as smoke and discoloration at elevated screw rpms.

In addition to lower melt temperature and higher rate capability, the residence time for the material was also reduced with the extended design. At 30, 40, and 55 kg/hr the residence times were respectively: 24, 16, and 11 sec. with the aggressive design and were 21, 13, and 8 sec. with the extended design.

Other factors that impact melt temperature:

The zone temperature setpoints will obviously affect the resulting melt temperature. In this study a reverse temperature profile was selected to lessen the melt temperature rise associated with the melting zone. After melting, a single kneading block section was integrated into the screw design to minimize temperature rise inherent with mixing.

The role of melting and the energy being imparted in this zone by the motor is often underestimated. It becomes apparent that the screw design should perform its task without excessive shear inducement, and that an optimized melt zone is a good start. The use of wide kneading blocks and reverse elements for mixig will impart more energy into the process and further increase in the melt temperature, not necessarily a bad thing, but something that must be understood by the screw designer.

Temperature rise caused by pressure:

Often overlooked, pressure generation at the discharge of the TSE will cause an increase in melt temperature. The more restrictive the front-end, the higher the pressure and corresponding melt temperature rise, which can be estimated as follows:

$\Delta T\ (°C) = \Delta P\ (bar) / 2$

Units:
ΔT = Change in temperature in °C
ΔP = Change in pressure (1 bar = 14.503 PSI)

For example: If a TSE is processing 500 KGS/HR and the die pressure is 40 bar (580 PSI), then the associated melt temperature rise can be 20°C. ($\Delta T = 40/2$)

This formula is meant to be insightful, if not necessarily accurate, as screws rpms, the geometry of the discharge screw elements, temperature setpoints, etc. all play significant factors in the actual melt temperature.

Summary

Co-rotating twin screw extruders are used to process olefin-based polymer compounds for a myriad of products. Managing melt temperature and minimizing degradation results in high quality parts. The TSE screw design, front-end configuration, temperature settings and operating conditions all impact what the formulation "experiences" in the TSE process section and directly influences the properties of the final part. Managing the melt temperature in a twin screw extruder should be emphasized to achieve optimization of any polymer process.

References

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