Relevant process parameters for twin-screw compounding

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Introduction

The screw conveyor has a long history. The first screw conveyor was invented by Archimedes (ca. 212 BC) and his design is still in operation today for uses like irrigation or grain transport. Industrial use of screw conveyors became prevalent in the middle of the 19th century. With the development of industrial polymers in the first half of the 20th century, screw conveyors, in a design form known as an extruder, emerged as a significant tool for polymer processing.

Single extruders can be used to melt and shape polymers, but they are limited in their performance. Because they operate with a completely filled barrel under pressure, no venting or split feeding is possible and mixing capabilities are limited. To satisfy growing demands in the polymer industry for continuous mixing, R. Erdmenger developed and patented a co-rotating twin-screw compounder with intermeshing, self-wiping screws.

In this application note, various compounding tasks along with process-dependent and independent parameters are discussed. An overview of how to optimize the compounding process and screw configuration is introduced, along with information about the automated measurement of the retention time. In addition, recommendations for how to scale up from a small laboratory compounder to a bigger pilot plant or a small-scale production extruder are presented.

The compounder

The main compounding steps in a parallel twin-screw compounder are feeding, melting, conveying, mixing, venting, and extrusion of the homogenized product (Figure 1). In the feed zone, solid material is fed by the volumetric or gravimetric feeder. Air is removed and low-density material is compacted. In the next step, the material is moved forward and heated up in a partially filled, non-pressurized conveying section. In the first mixing zone, the material is melted and plastified. The mixing zones are filled completely with material. A conveying zone follows and can be used for venting, split feeding of fillers, or liquid feeding.

Alternating mixing and conveying sections then follow to achieve a homogeneous product. The conveying screw elements within the venting zone are used for venting volatiles and air, either at ambient pressure or by vacuum. The role of the extrusion section is to build up pressure and shape the material. In most of the applications, a strand is extruded, which is then cooled in a water bath and cut into pellets.

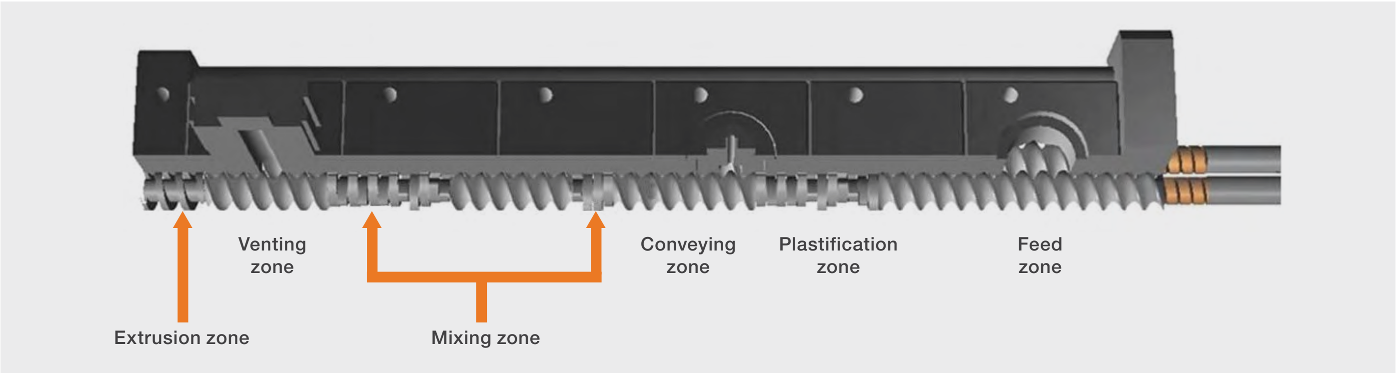

Figure 1: Barrel and screw layout.

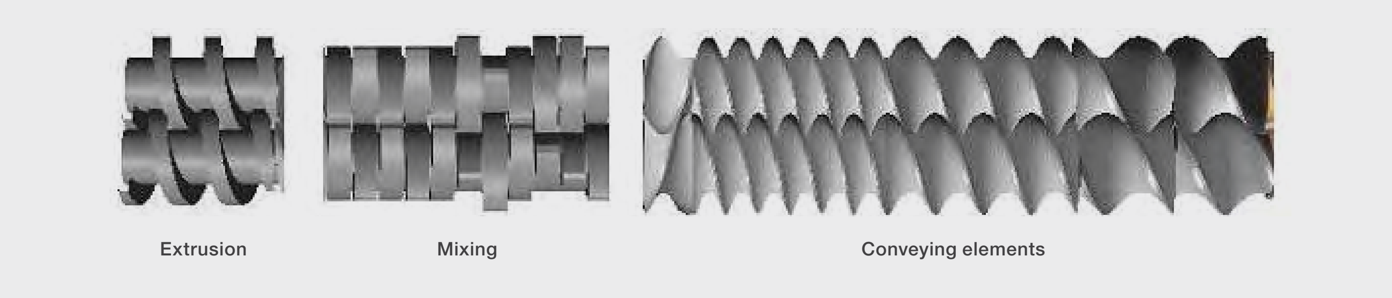

Figure 2: Screw elements.

The screw elements

Due to the segmented screw design, the assembly of the screw is variable. The most commonly used screw elements are self-cleaning and intermeshing conveying elements with shapes designed according to Erdmenger. The other screw elements are designed for mixing, extrusion, or special distributive mixing elements (Figure 2).

Processing parameters and dependencies

Parameters such as material throughput, the residence time or distribution of the material in the system, or the melt temperature depend on or can be adjusted via various factors.

The throughput has significant influence on the residence time. A higher throughput decreases the mean residence time and the width of residence time distribution (Figure 3).

The influence of the screw speed on the residence time is rather low. Backward-mixing elements have a high impact on the residence time and distribution increases. The main effect on the melt temperature comes from the screw speed and feed rate. A higher melt temperature is measured due to mechanical energy input in the mixing zones at higher screw speeds (Figure 4).

Scale up

After successful trials with a small-scale laboratory compounder (Figure 5), transferring the process to a bigger pilot plant or production compounder is always a challenge. The basic requirements are to use the same or at least a similar barrel geometry and the same screw configuration in both compounders. The residence times and melt temperatures should be similar to those in the laboratory test, and the operation of the compounder should be adiabatic. In the first approach, the screw speed and temperature profile should be the same as in the laboratory trials. The starting feed rate is calculated according to the rule of Schuler.[1] The specific energy is then adjusted by changing the throughput. The main energy is generated by the shear energy of the screws. The scale-up is limited because of the available surface of the barrel and its relationship to the volume; the rate of heat transfer (heating or cooling) decreases with the increased barrel diameter. The volume increases by a power of three, but the surface area increases only by a power of two.

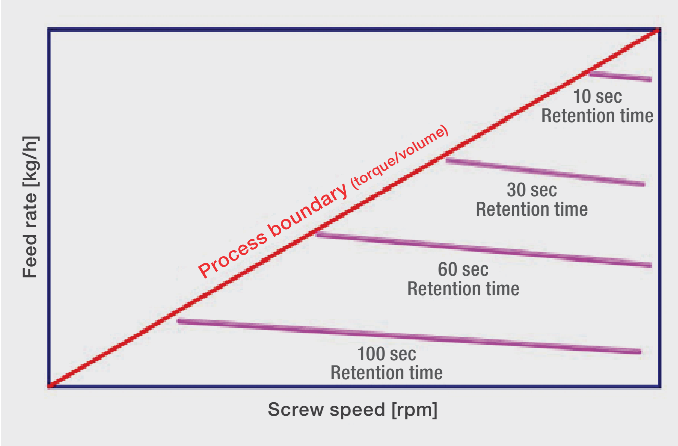

Figure 3: Residence time and feed rate.

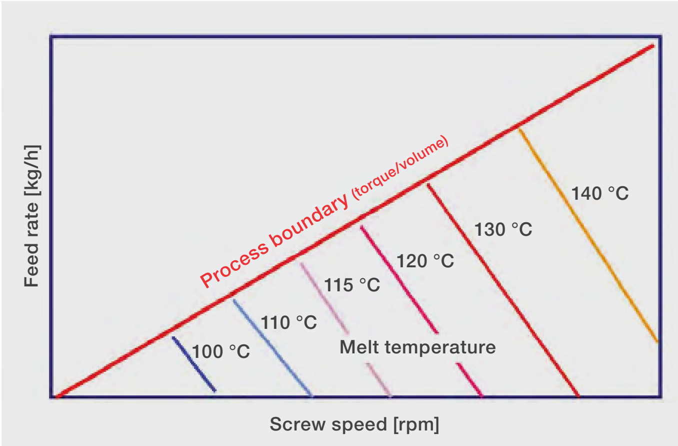

Figure 4: Residence time and screw speed.

Figure 5: Thermo Scientific Process 11—11 mm lab scale screw compounder.

A test was conducted on the laboratory-scale Thermo Scientific™ Process 11 Twin-Screw Extruder with a throughput of 1 kg/h and a screw speed of 200 rpm. These settings resulted in a specific energy of 559 kJ/kg and a residence time of ~55 s. To upscale to the Process 16, a 16 mm compounder, the throughput according to the rule of Schuler should be 3 kg/h. The measured residence time and specific energy under these conditions in the Process 16 were significantly lower than on the Process 11 Extruder. A correction of the feed rate to 2.5 kg/h generated a result similar to the smaller-scale residence time and the specific energy (566 kJ/kg) (see Figure 6).

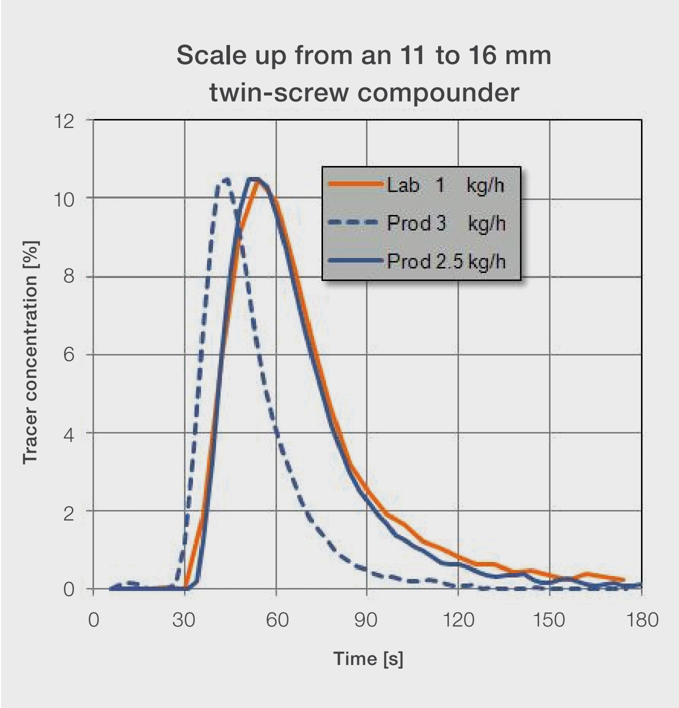

Figure 6: Residence time for scale up tests.

Conclusion

When scaling up from a laboratory-scale compounder to a larger unit, the theoretical factor for the throughput must be adjusted. The residence time is an important process parameter for the scale-up. Instead of measuring the residence time with a tracer and stopwatch, it is better to replace the stopwatch with a camera system and analyze the change of the color intensity of the tracer. The result is a residence time distribution with the average residence time as the maximum, which is the optimal outcome. With the knowledge of the smaller-scale processing parameters and the appropriate adjustments to factors such as those noted here, scale-up to a larger but otherwise identical compounder is quite possible.

Reference

1. W. Schuler (1996). Process Engineering Design of Co-Rotating Twin Screw Extruder, Dissertation, University of Wales Swansea, 1996.

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