Application Note
LR-55

Residence time measurements in Bench top twin-screw extruders

Rheology Application Notes

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Abstract

Co-rotating twin-screw extruders are widely used for dispersion of fillers, pigments and additives into thermoplastic materials. This paper outlines experiments on two different sized twin screw extruders, with results showing the relationships between screw speed and feed rate and its effect on residence time.

Introduction

When a new material is developed it is economic and convenient to make initial mixing tests on a small scale, before introducing the product onto a large capacity production line. When making a product on a small scale it is important to understand how different operating conditions will affect product quality.

Experimental method

The experiments were carried out on PRISM 16 mm and 24 mm bench top extruders, using a full range of screw speeds and federates and at two different length to diameter ratios on each extruder.
A 600 micron powdered Low Density PolyEthylene Exxon grade LD 600 BA of Melt Flow Index 20 was chosen because of future planned experiments with even smaller extruders.
The extruders were operated with open discharge to eliminate the effects of die pressure over the wide range of feed rates tested.

Twin screw mixing

A schematic of the twin screw process is shown in figure 1.
The important factor to notice is how feed rate and screw speed are independent.
A co-rotating twin screw extruder has excellent conveying capacity. For this reason it is normal to meter raw materials into the barrel. This has the advantage that several feed streams can be dosed, in a controlled way. But more importantly the screw speed of the extruder can be changed to achieve different mixing effects.
Among these residence times which will be explored in this paper.

Equipment

Figures 2, 3 and 4 describe the two extruders used. These were PRISM co-rotating twin screw compounders, with the ability to extend the barrels and screws to 40:1 L/D. Both have screw speed range to 1,000 rpm, and the motor powers are scaled in approximate proportion to the volume of the extruder.
The geometry of the screw profile is similar in terms of centre line spacing and channel depth.

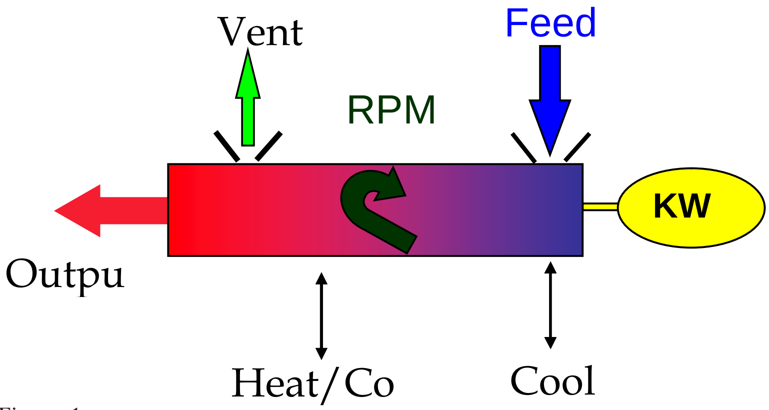

Figure 1

	Screws	Power	Maximum RPM	L/D ratio
Eurolab 16	16 mm	2.5 kW	1,000	25:1 & 40:1
TSE 24 HC	24 mm	9.0 kW	1,000	28:1 & 40:1

Figure 2

Figure 3: PRISM Eurolab 16 XL

Figure 4: PRISM TSE 24 HC

Screw configuration

Both extruders were fitted with two stage screw configurations, as shown in figures 5A and 5B. These ensured efficient melting of the polymer and sufficient energy input to avoid flood feed limits. For the longer barrel 40:1 extruders, the extra barrel length was set with only conveying screws to assess the energy required to transport the melt.

Experimental procedure

By selecting operating conditions across the full range of feed rate and screw speed, we could measure the effects of these variables on product residence time in the extruders. Feed rates were chosen to scale up volumetrically between the two extruders. The volume ratio is 3.375 and the motor power ratio approximates to this.
By running samples at the wide range of conditions outlined in figure 6, and measuring energy inputs and residence times, some predictable results were obtained.

Results

1. Residence Time

This chart (figure 7) shows how feed rate has as great an impact on residence time as does screw speed.

The results show how doubling the screw speed has less effect on residence time than changing feed rate.

Really long residence times are achieved by feeding at low rates. This has an impact on the size of extruder used for reactive processes.

When comparing residence times, it is important to consider the free volumes.
In the case of the 16 mm 25:1 with the 24 mm 28:1 the free volumes are 68 ml and 255 ml. If feed rates are scaled in a similar ratio, we can compare if the performance of the two extruders (figure 8).
At equivalent feed rates, you can see that the 24 mm and 16 mm have very similar curves.

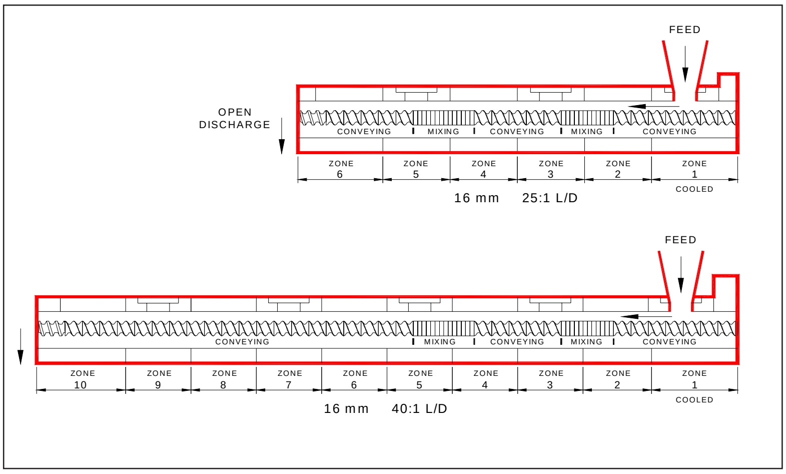

Figure 5A

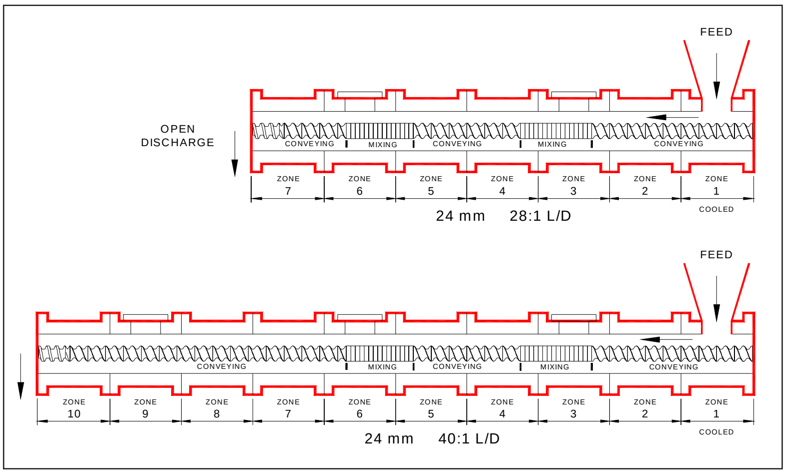

Figure 5B

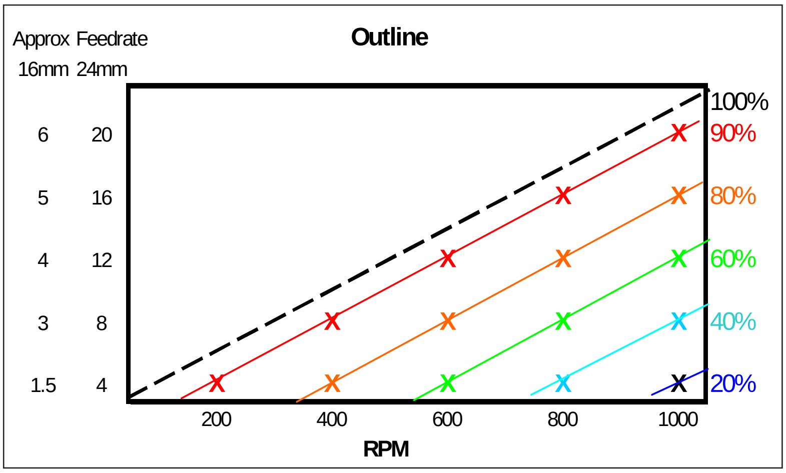

Figure 6

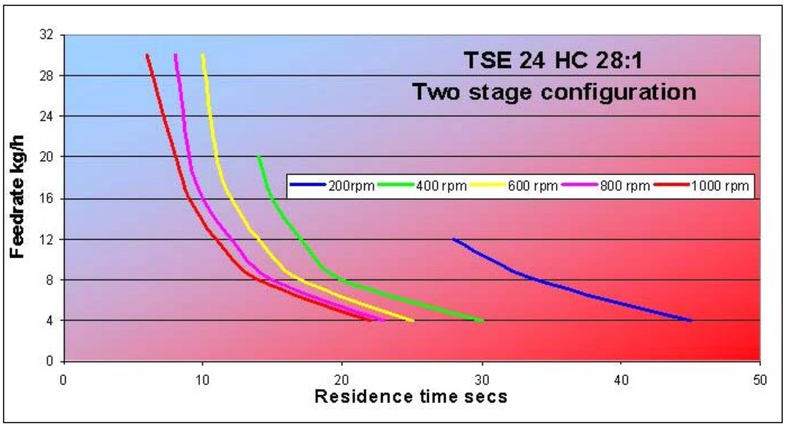

Figure 7

3. Effect of Barrel length and feed rate on Residence Time

Figure 9 compares the residence time in the 16 mm extruder, with two barrel lengths of 25:1 and 40:1 for different feed rates.
At all feed rates, the longer barrel extruder shows consistently longer residence times.
The same pattern can be seen with the 24 mm extruder at 28:1 and 40:1 L/D (figure 10).
The additional time for increasing the barrel length is between 10% (low rates) and 30% (high rates).

4. Effect of Screw speed and feed rate on Degree of fill

Figure 11 compares the degree of fill in the extruder for different feed rates at different screw speeds in both 16 mm and 24 mm extruders.

Greatest degree of fill is achieved at the highest feed rates and lowest screw speeds (figure 11).
Conversely low feed rates at highest screw speeds give smallest degree of fill.

Conclusions

1. At a fixed feed rate, increasing screw speed will reduce the residence time in the extruder.
2. At a fixed screw speed, increasing feed rate will also reduce the residence time in the extruder. This has a lager effect than changes in screw speed.
3. Increasing the L/D of an extruder will obviously increase, even if the extra length is only conveying screws. If that extra length included mixing sections then even longer residence times would be observed.
4. Degrees of fill in the extruder can be calculated from the residence time and feed rate data at a given screw speed. The shortest residence times are achieved by running at the highest possible federate at a given screw speed. To maximise residence times, the feed rate and screw speed must be reduced.

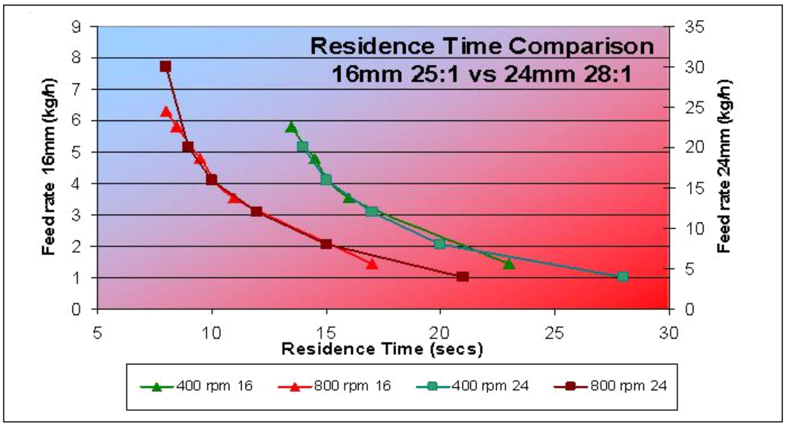

Figure 8

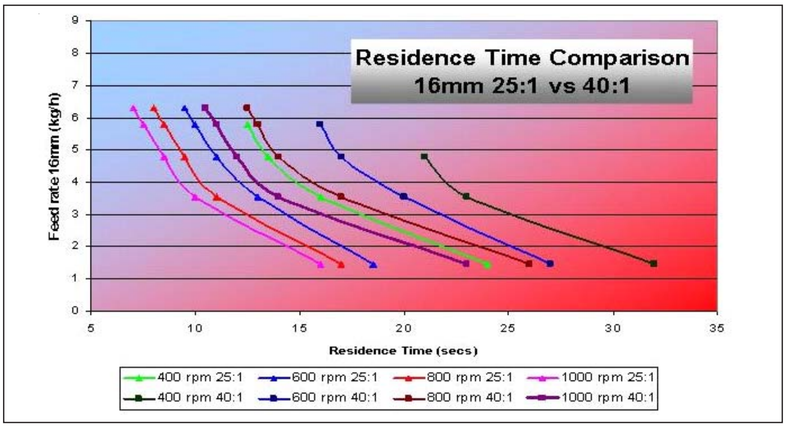

Figure 9

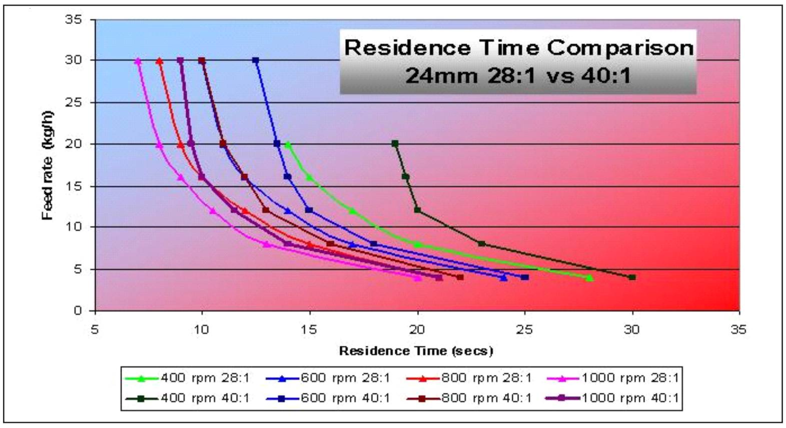

Figure 10

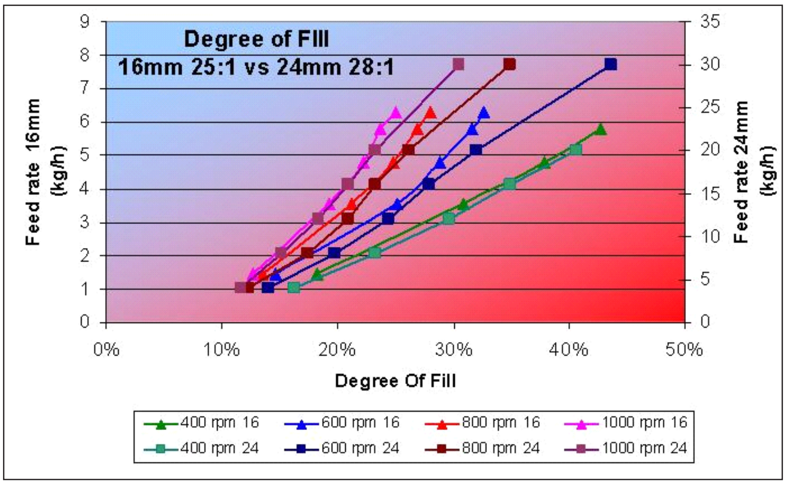

Figure 11

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