

SCREW AND BARREL DESIGN FOR GROOVED FEED VS. SMOOTH BORE EXTRUDERS

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Abstract

Grooved feed extruders (GFE) for quality production at lowest costs require screw and barrel designs capable of achieving gradual increases in pressure along the extruder and low friction in the feed section. Barrier-melting and mixing zones must be adapted to higher rates compared with smooth bore extruders (SBE). Because of reduced energy-losses new GFE-designs are no longer water cooled but use ceramic heating-/air-cooling-devices. Performance data of GFEs and SBEs represent differences in output and quality esp. at high speeds. Pros and Cons are discussed with respect to extruder downsizing, flexibility, regrind processing and vented extrusion, leading to preferred applications for GFEs and SBEs.

Introduction

Optimum design for single screw extruders is not a fully mature technology where all issues have been settled. New designs and variations of existing designs are still being developed.

Advances in extrusion technology are forced by the requirements of plastics processors. In the recent past, more rapid product changes and several new resins have led to a growing demand for a versatile high performance extrusion technology with outstanding throughput rates and excellent mixing quality for different resins, including regrinds, processed without changing screw or barrel.

Single Screw Designs

The well known barrier-screws with different dynamic mixing elements can be considered as the basis of the evolutionary development of today's extrusion systems [1]. Through the years a wide variety of barrier screw designs has been developed. Most of them have been designed and applied in North America. The "American" barrier section is usually entered from a smooth-bore feed zone and followed by a metering section. Compared to conventional metering screws with mixers, barrier screws are known for better melt quality and better output pumping stability at higher throughput rates.

Processing powdered resins such as high-molecular-weight PE-HD on smooth-bore extruders results in unacceptable low throughput rates. Axial or spiral grooves cut in the barrel along the feed section turned out to be an excellent solution to this problem. The basic principles of grooved barrel extruders were elaborated in Europe in the late 1960's [1]. Due to the improved friction of the solids at the grooved barrel, the throughput rate is controlled by the solids conveyed in the feed zone. This is valid for powdered resins as well as for pellets.

The grooved section of the barrel is usually cooled and thermally separated from the following heated barrel zones to ensure the solid conveying mechanism. This need refers to a screw design, which created much higher pressures in the feed zone compared to the backpressure at the screw tip by non-adapted melting and metering rates of the subsequent zones. Extruding polymers with higher melting temperatures than polyolefins was nearly impossible with this extruder design.

Screws for grooved barrel extruders need a feed section geometry that properly matches the solids conveying rate to the melting rate, pumping rate and mixing capability. This requires a shallower screw channel in the feed zone or adaptations to the flight pitch and flight width.

The main advantages of grooved barrel extruders are higher specific throughput rates and the fact that output is not or at least less influenced by the backpressure of the die. They are in widespread use in Europe and they have displaced smooth-bore extruders in many applications, in particular in the field of extrusion of polyethylenes and polypropylenes [1].

While the metering and pumping characteristic of smooth bore extruders is defined by the sections of the screw which are partially or totally melt filled, the output behavior of grooved feed extruders is controlled by the metering processes within the feed zone. Any subsequent screw zone will have to operate with a predefined throughput rate. This means that there is a strong influence of bulk properties like bulk density and frictional behavior.

For a given resin the specific throughput rate of grooved barrel extruders depends on the geometry and the number of grooves as well as on the diameter, the channel depth, the pitch of the feed section and the flight width of the screw [1, 3].

$$\dot{m} = \rho_S \cdot n \cdot D^3 \cdot k \left(\frac{\mu_{eff}}{\mu_S^{1.2}} - 1.3 \right)^{1/6} \cdot \left(\frac{h}{D} \right) \cdot \left(\frac{T}{D} \right) \cdot \left(1 - \frac{2.3b}{D} \right) \cdot \left(1 + 0.9 \cdot \frac{t_{max}}{D} \right) \quad (1)$$

There is a linear increase of throughput with increasing screw speed up to a certain limit where the formation of a melt film in the grooves destroys the solid conveying mechanism. The classical concept of screw design for grooved barrel extruders generates an extremely high pressure of 1,000 to 1,500 bar - or sometimes even more - at the end of the feed section to force the material through the downstream sections of the screw.

These high pressures and resulting high friction between solid resin particles and the steel of screw and barrel cause some severe disadvantages. About 10-20 % of the actual drive power in this case is lost to the cooling system of the grooved barrel section; there is the risk of heavy wear and an overload torque of at least 2 times the nominal torque is needed to start-up the extruder with a filled hopper.

A solution to this problems is a "pressure relieved" grooved section. This can be achieved by enhancing the conveying rate of the downstream sections e.g. by increasing pitch or/and channel depths [2]. The best concept to ensure an excellent melt quality at the same time is the integration of a barrier screw design.

Barrier Screws for Grooved Barrel Extruders

The barrier zone can - depending on operation point and resin - generate a substantial pressure. This results in a pressure at the end of the feed section that is at least lower than the backpressure of the die.

The homogeneity of the melt has to improved by suitable mixing sections, which must be designed for the regularly higher specific throughput rates compared to smooth bore extruders. A dispersive mixing spiral shear element e.g. tears up melt regions of different viscosity. It may be followed by a rhomboid distributive mixing section. Both zones provide a good heat transfer to the wall of the barrel. And, due to their spiral geometry, they are can be designed designed for balanced pressure [4].

When processing regrind material there is a reduction in bulk density, responsible for a lowered throughput rate, which can partially be minimized by using an increased channel depth in the feed zone, possibly in combination with increased flight width for smaller sized extruders.

If the described screw and barrel design is consequently applied grooved feed technology can also be for

technical polymers with higher melting temperature like PA, PC, PET, PBT, PVDF e.a. Grooved feed sections no longer require intensive cooling but even heating. Therefore a new grooved feed design including electric heating in combination with air-cooling has been developed and introduced into practical operation, allowing the extrusion of a very broad range of polymers with polyolefines on one side and technical polymers on the other, Figure 1. Necessary temperature setting of the feed section will vary from 50 °C (e.g. PE-LD, EVA) to 250 °C (e.g. PA, PC).

The application for vented extrusion (e.g. PS, ABS, PVC-P, PC) is also advantageous because of the nearly constant specific throughput rates even at high screw speeds. In this case the goal is not to improve specific rates in general, but to keep them on the desired level in the high speed range. In many applications an integration of a gear pump will solve the problem of energy efficient pressure generation to feed the extrusion die. Due to the lowered back pressure the design of the second section of the screw including the venting zone allows a deep cut, preferably double flighted, metering section with minimized energy dissipation.

Table 1 summarizes the pros and cons of the competing extrusion concepts and tries to point out the possible combination of pros by an improved grooved feed / barrier-screw extrusion system with efficient barrel temperature control devices.

Direct Drive Design

Stimulated by developments in twin-screw extruders, a new high speed, direct drive single screw extruder with 35 mm diameter an L/D=27 was designed and introduced into different applications. An energy optimized plasticating unit can improve the efficiency by up to 20-30 %. The new machine design is noted above all for its direct drive without any reduction gear [5].

The temperatures of the extruder barrel including the feed section is controlled via the use of new heating / air cooling elements with good heat conducting ceramic elements over the entire surface of the barrel. This allows excellent heating as well as convective cooling if required over a wide temperature range (up to 350 °C). Figure 2 show a cross sectional view of the machine, which has been scaled down in the meantime to a 25 mm version as well.

Experimental Program

Several extrusion trials were carried out with a laboratory extruder of 50 mm diameter and 28:1 L/D. The screw was fit in a special designed extruder to realize screw speeds far beyond the usual range by using an AC motor. Trials had been run with two versions of screw /

barrel combinations. First a grooved feed system and second a smooth bore system have been tested, each with an adapted barrier screw; only the channel depth profile along the screw had to be adapted to the metering characteristics of either smooth or grooved barrels.

The resins for the experimental analysis were chosen to cover a broad range of different properties (Table 1 and Figure 3: PA 12 with different pellet shapes) and PA 11, PVDF, PA, PE-LD (Figure 4 and 5).

The screw speed for each resin was varied between 10 and 350 1/min, while the flow resistance of the die was not changed.

Experimental Results

The results of the experimental analysis are shown in the performance graphs (Fig. 3 to Fig. 5). The output rates increase in an almost linear fashion with screw speed up to maximum throughputs. A better impression of the linear correlation between throughput rates and screw speed can be derived from the calculated specific rates shown in Fig. 3, which illustrates the significant differences between the two extrusion systems. While the specific throughput rates are much lower for the smooth bore system, the melt temperatures are significantly higher. This limits the possible screw speed for smooth bore systems whenever melt temperature limitations have to be considered.

As screw speed is increased the screw design provides an excellent control of melt temperature (Fig. 4). All resins are far from exceeding the temperature ranges recommended for processing. The temperature elevations mainly depend on specific throughput, melt flow index and shear thinning behavior. Almost Newtonian plastics show more sensitivity to increasing screw speeds. The mixing quality of the screw - examined by visual inspections - turned out to be excellent for all resins as well.

A large portion or even all of the pressure at the screw tip is generated by the first metering and the barrier zone of the screw as represented in Fig. 5. The extrusion of nearly all tested materials over the speed range leads to zero or very low pressures at the end of the feed zone, indicating that the melting and transport capacity of the barrier zone matches the solids conveying rate.

At higher screw speeds and/or higher backpressures the transport capacity of the barrier zone does not keep up with the solids conveying rate. The result is an acceptable increasing pressure at the end of the feed section, esp. for PA 11 and PVDF.

This influence can completely be explained by the increasing dissipation due to the pressure dependent viscosity of the melt. There is not an additional negative effect of

decreasing throughput as can be observed for smooth-bore extruders.

Conclusions

The experimental data presented in this paper shows that the combination of grooved barrel conveying and barrier melting mechanism can substantially enhance the performance of screws for single screw extruders. Furthermore, the improvements in throughput rate and melt temperature control are evident for a broad range of resins. Further developments like gearless extruders with high screw speed or melt separation techniques [5,6] may base on optimized grooved feed systems.

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References

- [1] Martin, G.: Der Einschneckenextruder - Grundlagen und Systemoptimierung, VDI-K, Düsseldorf, 2001
- [2] Potente, H: Der Nutbuchsenextruder muss umgedacht werden, Kunststoffe 78 (1988) 4, S. 355 - 363
- [3] Stenzel, H.: Grundlagen zur verfahrenstechnischen Auslegung von Barrierschnecken in Glattrohr- und Nutbuchsenextrudern, Dissertation, Universität GH Paderborn, 1992
- [4] Wortberg, J.; Michels, R.: Barrier Screws for grooved barrel extruders - High performance extrusion for a broad range of resins, SPE-ANTEC, Toronto, 1998, pg. 48 - 52
- [5] Wortberg, J.: Increasing efficiency through innovative machine technology, Kunststoffe - Plast Europe 89 (1999) 1, pg. 12 -15
- [6] Kaczmarek, D.; N.N.: Screw sleeve cuts extruder length by nearly one-half, Modern Plastics International - K'01 Show Daily, 31.10.01, pg. 7

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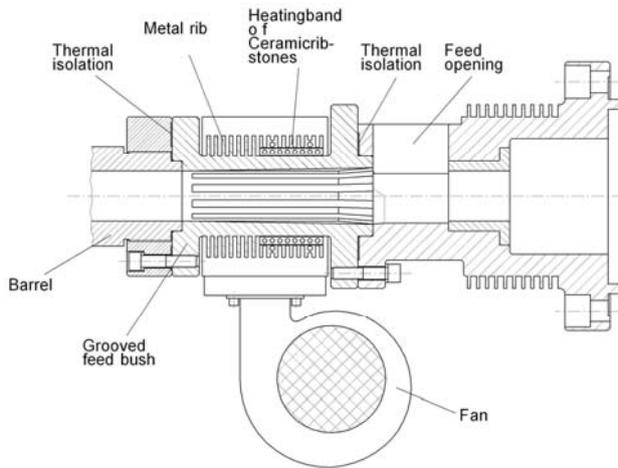


Figure 1: Grooved feed section with electric heating/ Air cooling

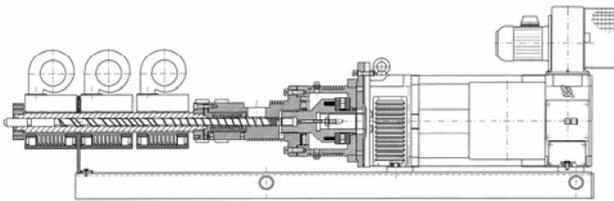
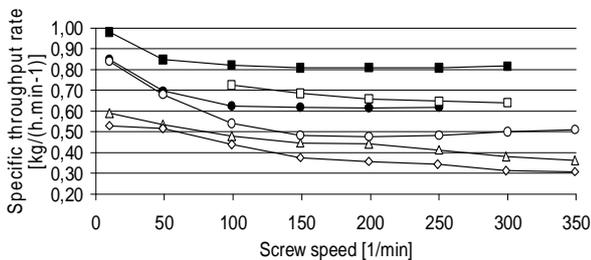
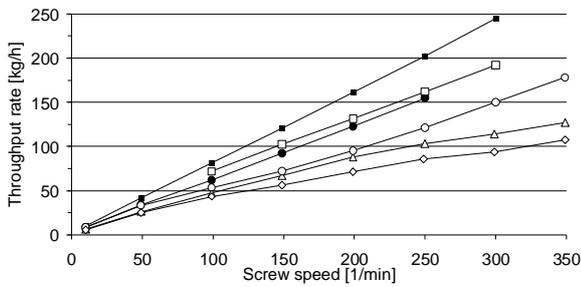


Figure 2: High Speed Extruder with direct drive 35/27D (University of Essen, esde Maschinentechnik GmbH, ETA Kunststofftechnologie GmbH)



■ Resin A, Grooved feed bush ● Resin B, Grooved feed bush
 ▲ Resin C, Smooth feed bush □ Resin A, Smooth feed bush
 ○ Resin B, Smooth feed bush ◇ Resin D, Smooth feed bush

Figure 3: Throughput vs. screw speed for grooved feed and smooth bore extrusion systems (PA12 different shapes)

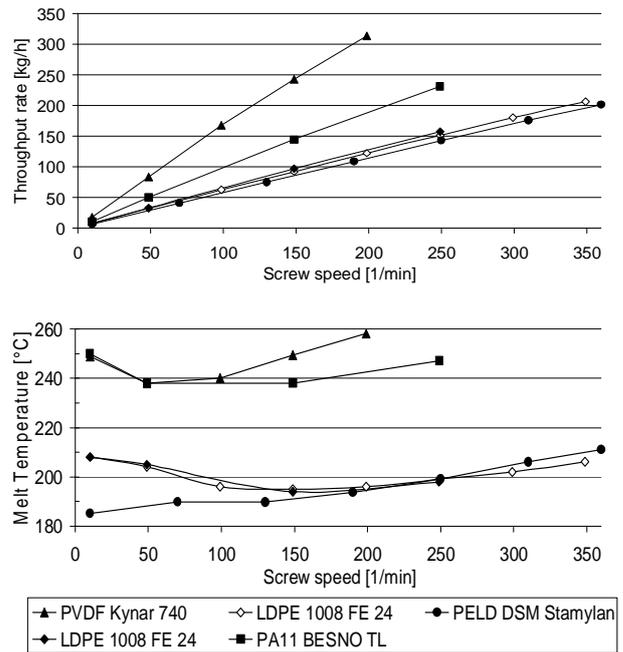


Figure 4: Throughput rates and melt temperatures vs. screw speed for different polymers

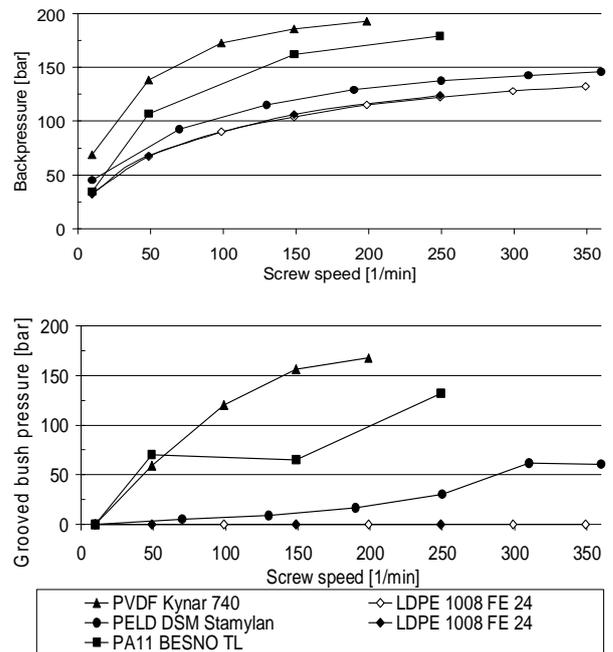


Figure 5: Back pressure and grooved bush pressure vs. screw speed

| Designation | Shape | Dimensions (mm) |
|-------------|--------------------------|-------------------------------------------------------|
| Resin A | Spherical basis pellets | $3,4 < \phi < 3,8$ $2,5 < h < 2,8$ |
| Resin B | Elliptical basis pellets | $2,1 < a < 2,3$ $3,1 < b < 3,3$ $2,5 < h < 2,6$ |
| Resin C | Spherical basis pellets | $3,5 < \phi < 4,1$ $2,8 < h < 3,0$ |
| Resin D | Elliptical basis pellets | $2,0 < a < 2,2$ $2,7 < b < 2,9$ $3,4 < h < 3,6$ |

Table 1: Resin Shapes

| | Reported arguments from different references | |
|---------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| | Pros | Cons |
| Smooth barrel/screw system | <ul style="list-style-type: none"> - Low wear - Wide range of polymers - Good processing of regrind material - Suitable for vented extruders | <ul style="list-style-type: none"> - Throughput rate dependent on back pressure - Higher melt temperature |
| Grooved barrel/screw system | <ul style="list-style-type: none"> - High specific throughput rate - Throughput rate independent on back pressure - Lower melt temperature - Lower specific energy consumption | <ul style="list-style-type: none"> - Water cooling of the feeding zone - Depending on bulk density and friction - Higher required torque - Higher manufacturing costs - Restricted to polyolefines |
| | Combination of pros | |
| Improved grooved barrel/screw systems | <ul style="list-style-type: none"> - No water cooling, electric heating/air cooling is sufficient - Heating of grooved zone applies to processing of technical polymers - Low pressure in grooved feeding zone (\leq back pressure) - No critical wear - Wide range of polymers - Controlled melt temperature - Venting is possible | |

Table 2: Comparison of a grooved barrel/screw system with a smooth barrel/screw system