The Case for Grooved-Feed Barrels
for
Processing LDPE-LLDPE

Presented By
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INTRODUCTION: Processors of blown film are faced with the question, "What type of extruder is best for my application?" The word, "best," like beauty, is a matter of the beholder. Nevertheless, clearly grooved barrels offer significant processing advantages in many applications. The purpose of this paper is to explain how grooved feed barrels work and the advantages (and pitfalls) that follow.

SPECIAL NOTE: In order to write this paper, I relied heavily on input from Andrew Wheeler and Matt Bangert. For their effort, I wish to thank them. Any errors that may have occurred in my understanding from them, though, are my responsibility completely.

DEFINITION: Most extruders have a separate barrel section under the hopper. If this section is smooth, the extruder is call a smooth barrel extruder. If this portion of the barrel is grooved, then the extruder is call a grooved barrel extruder. Sometimes, this portion of the barrel is called the, "Feed section." Unfortunately, the first part of the screw is sometimes called the feeding section of the screw and this can lead to confusion. In this paper, we will use the term "grooved barrel" exclusively.

HOW GROOVED BARRELS WORK: Single screw extruders convey polymer pellets by means of friction. The barrel, by means of frictional contact with the pellets, drags the material over the screw against the helix and the pellets advance. This is true even though the barrel is stationary. The process can be pictured as a stationary screw and a revolving barrel about the screw. Or, if you picture a nut on a bolt, the nut will only move forward on the revolving screw if the nut rotates slower than the screw. Similarly, the plastic pellets will only move forward if the drag from the barrel is greater than the resistance of the pellets on the screw.

In an extruder equipped with a totally smooth bore, there is a very significant amount of slippage in the system as the pellets tumble and slide. The pellets act like ball bearings where the contact between the barrel and pellet surface is small. This is why the apparent compression ratio is typically between 2.5 and 4.5:1 for smooth barreled extruders. (The apparent compression ratio is the ratio of the screw's thread depth in the first flight divided by the screw's thread depth in the last flight.) In a sense, the apparent compression ratio of a properly functioning screw is a measure of how well pellets are transported.

In a smooth bore barrel, the pellets follow a helical path in the solids conveying section of the screw. That is, they are pushed along the helix of the screw taking a slow winding path.

In a "grooved" feed barrel, one or more grooves are added to the bore of the barrel under the hopper and into the solids conveying zone. The grooves are usually parallel to the bore. The grooves continue beyond the opening in the hopper for 1 to 6 L/D's. Three manufacturers (Ref.: 1, 2 , 3) of blown film equipment were surveyed and they all report a typical L/D ratio of 3.5:1. The grooves do not extend beyond the solids conveying section as they work only on solids rather than melted material. Therefore, grooved feed sections are intensively water cooled (Ref. 1,2,3,4) to prevent premature melting.

Specific guidelines for screw geometry are proprietary. However, general guidelines (Ref. 3) are that the extruder diameter (in inches) divided by 0.4 will give the number of grooves. The same reference suggests groove width of 0.18 to 0.38 inches and a taper of 3 degrees for the grooves. Besides rectangular grooves, the grooves may be trapezoidal or hemispherical (Ref.: 2). Helical grooves have not met with widespread success.

Thread depths in the solids conveying zones are shallow compared to smooth bore barrels. This is because the increased efficiency of transportation means that large depths are not necessary to fill the metering section of the screw. Typical flight depths between 0.143 to 0.196 inches are reported (Ref. 3).

WHY GROOVES WORK: In effect, the pellets become trapped in the grooves and advance against the helix of the screw. So, instead of advancing slowing along the helix of the screw, the pellets advance forward in the grooves pushed by the helix. This means that there is a tremendous increase in transportation. Typically, apparent compression ratios are only 1:1 and yet still allow the metering section of the screw to be filled. This indicates very efficient transportation.

It may appear, that such efficient transportation is impossible because it implies that transportation is at 100%. This is not the case. Transportation can never be perfect. However, it must be remembered that polymers expand significantly (many in the area of 25%) in volume as they are heated to process temperature. This increase in volume allows the metering section to be filled with less than perfect transportation and with only 1:1 compression ratio screws. In fact, screws designed for use with grooved barrels not only use low compression screws, they typically increase the pitch of the screw (Ref.: 1,2) to accommodate the increased volume. Alternatively, the thread depth is increased (Ref.: 3, 5) although in practice this is less common probably because the increased helix angle makes for a more efficient pump for molten polymer (Ref.: 6)

ADVANTAGES OF GROOVED BARRELS

This increased pumping efficiency of the grooved barrel extruder has several interesting results. These results become advantages for blown film applications and LDPE and LLDPE in particular.

HIGH PRESSURE DEVELOPMENT: In a smooth bore extruder, the pressure in the solids conveying zone of the screw has been measured (Ref. 11) and shown to be very low. Often, for the first 5 flights, pressure is so low that pressure gages read zero. Typically, pressure rises through the melting section of the screw and reaches its highest point at the end of the transition zone (Ref.: 11).

In a smooth bore extruder, the metering section of the screw builds pressure to overcome the dies resistance to flow. As the metering section of the screw is deepened, its ability to build pressure decreases and output will decrease when the resistance of the die is greater than the pumping ability of the meter. The actual pumping efficiency of a smooth bore barrel's metering section will only be about 10% or less (Ref.: 7). This limits the ability of a smooth bore barrel to build pressure to perhaps 6,000 psi in production sized extruders (Ref. 2).

In a grooved feed section extruder, however, pressure to overcome the die's resistance is not developed exclusively by the metering section of the screw. Instead, pressure is developed in the solids conveying zone by the grooves. Depending on design of the grooves, pressures have been measured in the 10,000 to 20,000 psi range (Ref.: 2, 5) and pressures as high as 45,000 psi have been reported (Ref.: 8)

These higher initial pressures have several advantages. Higher pumping pressures generate higher outputs.

Alternatively, more restrictive dies may be used at the same output. The maximum restriction in a die is often from the small opening of the die lips. Dies with smaller die gaps making the same thickness films, are like to make more uniform films because the draw down is lower (Ref. 1,2).

Higher pressures have purging advantages too. In the smooth barrel extruder, pressure in the first flights is about zero. When pigments and colorants are processed, the pigments rub off on the screw over time and accumulate like chalk on a blackboard. When the color is changed or a natural material is processed after a pigmented material, the very low pressures in the first part of the screw very slowly remove these pigments. This is roughly analogous to gently wiping the chalk of the blackboard with an eraser and slowly smearing the chalk in one direction. However, grooved barrels have a very high initial pressure. This scrapes the pigments off the screw very quickly. This results in very fast screw purging.

The same principle is true in the die although the pressure differential is not so great. That is, the higher pushing pressures in the die (available only from the grooved barrel extruder) allows faster change over from one color to another or one material to another.

HIGH OUTPUT: Because the grooves transport material so efficiently, the output from a grooved feed barrel extruder is higher than a smooth bore extruder. Generally, the output is approximately equivalent to the next size larger extruder (Ref.: 1,2). In other words, the output from a 2 inch extruder equipped with a grooved barrel is about equal to the output of 2.5 inch smooth barrel extruder; the output of 4.5 inch grooved bore barrel is approximately equal to a 6 inch smooth bore barrel.

This increased output comes about because of the grooved barrel's ability to generate much higher pressure than a smooth bore barrel. Essentially, the pressure generation is no longer a function of the metering section of the screw. This means that the output of a grooved barrel extruder is nearly linear (Ref. 2) with screw rpm whereas it is well known that smooth bore barrels have decreasing output at high pressures as is the case in blown film dies.

ENERGY EFFICIENCY: It seems that the energy efficiency of the grooved bore extruder may be higher that a smooth bore barrel. Reportedly (Ref. 2), grooved barrels may consume up to 30% less energy than smooth bore barrels. However, this comparison is difficult to make and, to be consistent, should only be compared to an efficient smooth bore extruder. Operating conditions clearly play a role (Ref. 9) as it has been noted that energy efficiency of grooved barrels processing LDPE can be from 45 to 80% efficient depending on the temperature of the cooling water (Ref. 9). Helical grooves also tout energy savings. (Ref. 9).

UNIFORM PRESSURE: Perhaps the single biggest problem in extruders is surging. Surging (pressure variation at the screw output) can come from many sources. However, the very high pressures achieved initially by the grooved barrel mean that the solid bed can be more consistent. It is the authors general experience, that pellets are not perfectly consistent in geometry even within one lot of material. Such irregular geometry affects the regular formation of the solid bed on smooth bore extruders. If the solid bed is not formed very consistently, it is likely that surging will result.

Because the grooved barrel extruder has a very high initial pressure, the solid bed is formed under high pressure very quickly. This means that the grooved barrel will surge less because they have a lowered sensitivity to pellet geometry.

In addition, grooved barrels, having a higher coefficient of friction, reduce surging (Ref. 2, 3, 4).

SLIPPERY MATERIALS: A unique advantage of a grooved feed section is its ability to handle slippery materials. While it is well known that smooth bore barrel cannot process slippery and viscous polymers and that grooved bore barrels can, this unique ability should not be overlooked with respect to the less slippery LDPE and LLDPE under discussion. It must be remembered that all sorts of processing aides, slip agents, lubricants, and so on are added to the polymer feed stocks of LDPE and LLDPE by blown film manufacturers. It is extremely likely that these additives will decrease output and/or increase surging in smooth bore extruders but not in grooved bore extruders. This opens up blends of LDPE and LLDPE materials for processing that simply cannot be processed with smooth bore barrels. (Ref.: 4).

LOWER MELT TEMPERATURES: It is well known that increasing screw speeds using a smooth bore barrel tends to increase the melt temperature. Often, this becomes the limiting variable that stops further increases in screw speed. Compressive screws are largely responsible for this increase in temperature as the polymer moves through the compression section (melting zone) of the screw (Ref.: 10) whereas a large amount of energy for melting is produced within the grooves of the grooved barrel extruder. The grooves are intensively water cooled and excess heat (that would otherwise prematurely melt the polymer) is removed (Ref.: 2, 4, 8,9,10, 12). Therefore, increasing screw speeds do not necessarily drive up melt temperatures drastically. Lowered process temperatures have obvious advantages.

MIXING

Mixing in single screw extruders is, in part, a function of the compression ratio. Generally, the higher the compression ratio, the greater the resistance of the screw to the polymer in the channel. Higher compression tends to increase mixing by forcing material backwards in the screw channel and over the tops of the screw flights because of higher pressure.

When the compression ratio is decreased, as in typical grooved barrel screws, mixing can suffer. Therefore, at least one mixing section (sometimes more) is employed. In addition, barrier screws are used to increase mixing in grooved barrel extruders. Mixing is extremely difficult to quantify and the author is not aware of good detailed studies of the mixing performance of smooth verses grooved barrels. The author's opinion (admittedly, without benefit of any science to back him up) is that the higher pressure capability of the grooved implies that more mixing sections, static mixers, or mixing sections with higher pressure drops can be employed to advantage.

GROOVED FEED SECTION PROBLEMS: The biggest problem with the acceptance of grooved feed sections by industry seems to be the inability to process fluff or reclaimed material that is commonly processed by smooth bore barrels. The basic problem is grooved barrels do not tolerate fluff well as premature melting is likely.

Two manufactures offered reasonable solutions to the author. The first was to produce negligible amounts of trim. While specifics were given to the author as to how to do this (Ref.: 1), the author did not receive substantive scientific information to reference. Therefore, the author suggests to the reader that they investigate this point first hand.

The other solution that was offered, was to pelletize the fluff separately in an extruder designed exclusively for this purpose. Dual diameter screws, for example, are capable of such pelletizing operations. The pellets thus produced are not reported to interfere with grooved barrel extrusion.

A lesser problem is wear. High pressures imply high wear. Wear resistant materials are now commonplace with the result that even the most wearing material (HMW-HDPE) yields 40,000 hours screw life (Ref.: 3).

CONCLUSION: The advantages of grooved barrels are so significant that increased acceptance for LDPE and LLDPE seem likely. Increasing pressure for more uniform output, more output, better output, and at increased efficiency (in other words market forces) will probably drive the increased acceptance.

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Synopsis: The Case for Grooved-Feed Barrels For Processing LDPE-LLDPE

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HOW GROOVED BARRELS WORK: Grooved barrels transport polymer pellets by means of generating a higher friction on the pellets than do smooth bore barrels. The greater friction changes the amount of pellets that are transported per revolution and the direction of pellets from helical to axial. This necessitates a change in screw design to accommodate the increased flow and intensive water cooling. Typical grooves are rectangular and axial with dimensions 3.5 L/D long, groove width 0.25 inches, and 0.125 inches deep. Screw pitch is increased as the pellets leave the grooves and melting occurs.

THE ADVANTAGES OF GROOVES:

High Pressure Development: Typical operational pressures for smooth bore barrels seldom exceed 5000 pounds while typical operational pressure for grooved bore barrels is about 7,500. The higher pressures generate significantly higher output from the same size extruder. The higher working pressures allow for faster purging of the extruder screw, transfer pipes, and die as well as more restrictive die design. This, in turn, allows for more uniform films since draw down is diminished. Additional mixing sections are used with grooved barrels to advantage. Because higher pressures are available from the grooves, the mixing sections' pressure drops do not result in a decrease in output.

Uniform Pressure: Smooth bore barrels have very low (often zero) pressure in the solids conveying zone while pressures in the grooved barrels' solids conveying zone are often in the 10,000 PSI range. The increased efficiency leads directly to a more orderly transportation and a subsequent reduction in surging.

Slippery Materials: Higher transporting efficiency allows slippery additives (that cannot be processed on smooth bore barrels) to be processed thus making grooved barrel extruders more flexible than their smooth bore counterparts.

Lower Melt Temperatures: The lower compression ratio screws used with grooved bore extruders results in melt temperatures that do not rise with increasing screw speeds. Thus, the increased output is not at the expense of film properties or processing range but can enhance properties.

Limitations Of Grooved Barrels: Wear and fluff are the two main concerns for blown film lines and grooves. Wear is reduced by using wear resistant lines and fluff should be repelletized before subsequent reprocessing.

CONCLUSION: The advantages of grooved barrels are so impressive that market forces will probably drive increased acceptance in the future.