

Why Screws are Designed the Way They Are

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The selection of the proper screw for a given injection molding or extrusion application can be critical to its success. Screw geometry — length-to-diameter ratio, profile, channel depth, compression ratio, helix angle and a host of special design features — has everything to do with how well the screw performs in a given application.

There are documented applications where customers have improved production rates or reduced cycle times by 30 or 40% simply by switching to an improved screw design. Similarly, reject rates have been lowered from more than 4-6% to less than $\frac{1}{2}$ of 1% by incorporating a custom designed mixing screw. And experience shows that the amount of color concentrate required to achieve optimum color mix can be typically reduced from 4% (of the total blend) to 2%, just by using an optimized screw design. When considering resin and concentrate costs, payback for an optimized screw and non-return valve design can be almost immediate.

So it would seem to make sense to optimize the screw to the greatest degree possible. On the other hand, many processors run a variety of different materials and find it too costly or time consuming to change screws every time they change materials. These processors ask for a General Purpose (GP) screw, hoping to run many different resins with reasonable effectiveness. In reality, though, a GP screw

will run very few materials well and a lot of effort and money has been invested trying to get a given level of throughput or quality out of a GP screw.

Does this mean that you have to buy a special screw for every different material you run? Not necessarily. There are groups of materials that have similar processing characteristics and they can often be processed with reasonable effectiveness on similar screws. The trick is knowing when to make a compromise that will maximize the number of resins that can be processed on a given screw, and when to optimize screw design so as to improve performance.

Let's look at what makes a screw function and then consider how these design features can be combined and fine-tuned to produce a screw that represents the "best compromise" ... the screw that will process the most materials at as close to optimally as possible.

SCREW DESIGN BASICS

The standard metering screw — single-flighted, single-stage — incorporates the following five features (see Figure 1):

L/D Ratio: The length-to-diameter ratio of the screw is the ratio of the flighted length of the screw to its diameter. Most injection screws have L/D ratios that range from an 18:1 to 24:1 ratio, while extrusion and blow-molding screws generally range from 24:1 to 30:1. L/D ratio can be a very important factor in screw design. Using the proper length screw is critical to optimizing your process. Certain materials and processes dictate different screw lengths. Injection molding screws, as a rule, are shorter than extrusion screws for a few reasons. A critical factor in extrusion is the “metering” or pumping section of the screw. This is the shallow section at the downstream end of screw which, in extrusion, is critical to overcoming head pressure. In injection molding, this isn’t a factor, so a screw designer can typically use this length for other functions of the screw. Other critical factors in extrusion, generally, are output rates and mixing. Both of these ends are easier to accomplish with a longer screw. However, because we are asking the screws to do more and more in injection molding these days, we are starting to see the utilization of longer L/Ds (i.e. 24:1) more frequently. However, some materials that are extremely heat sensitive dictate shorter L/D ratios, especially in injection molding. With these materials, it is especially important to tailor your screw to the materials you are running.

Screw profile: There are three zones in the flighted length of the typical screw. These are the feed section, the transition or compression section, and the metering section. Plastic first

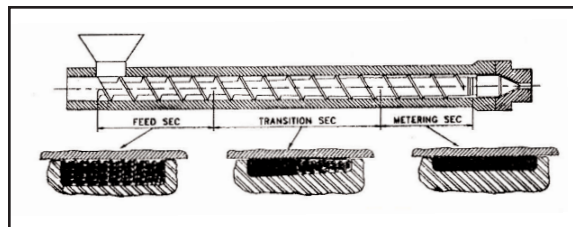


Figure 1. Illustration shows a standard single-flighted, single-stage feedscrew. Cross-sections show unmelted pellets in the feed section, partial melting in the transition (with segregation of melt and unmelt), and fully melted material in the metering section.

enters the feed section, where it is compacted, begins to melt and is conveyed down the barrel to the transition zone. Here is where most of the compression and melting takes place as the root diameter of the screw gradually increases and channel depth decreases. Final melting takes place in the metering section, where it is conveyed forward along a constant depth while reaching a temperature and viscosity that is necessary to form parts.

The screw profile is defined as the length, in diameters or flights, of each of the three zones. A 10-5-5 screw indicates a 20:1 L/D screw with 10 diameters of flighted surface in the feed zone, 5 diameters in the transition zone, and 5 diameters in the metering zone.

Channel depth: Feed and transition zone channel depths are dependent upon the selected compression ratio and screw profile. The resin being processed determines the channel depth of the feed and metering zone. A deeper feed zone can lead to higher output rates, however it is critical that this feed section be properly accompanied by a melting and metering zone that is efficient enough to handle the increased material

feeding. A screw is limited in output rate by its melting capacity, otherwise the melt quality off the end of the screw suffers dramatically.

Compression ratio: The ratio of the channel depth in the feed zone to the channel depth in the meter zone is the compression ratio. It typically ranges from 1.5:1 to 4:1 for most thermoplastic materials. Compression ratio is one of the most often talked about characteristics of screw design, and rightfully so. Depending on the melting characteristics of the resin, compression ratio can be either very high or very low. For instance, rigid PVC, a heat- and shear-sensitive material, typically requires a compression ratio on the lower end of the above range, while a high melt index polypropylene would dictate a ratio on the higher end of the range. Also, while compression ratio is very important, you can't forget about the "compression rate" of the screw, which factors together the compression ratio and the length of the compression zone of the screw. Think of compression rate as "melting rate." A high compression rate accomplishes compression faster and this rapid melting can damage heat-sensitive materials like PVC. For this reason, compression rate is almost more important than compression ratio.

Helix angle: This is the angle of a screw flight relative to the plane perpendicular to the screw axis. Only in special circumstances will the helix angle be altered, such as with special barrier screws, two-stage screws, or in the development of mixing sections. On a conventionally flighted, square-pitch screw design, the helix angle is approximately 17.7 degrees. Depending on what is trying to be accomplished with the output and shear rates of the screw, this angle can be increased or decreased. It stands to reason that the

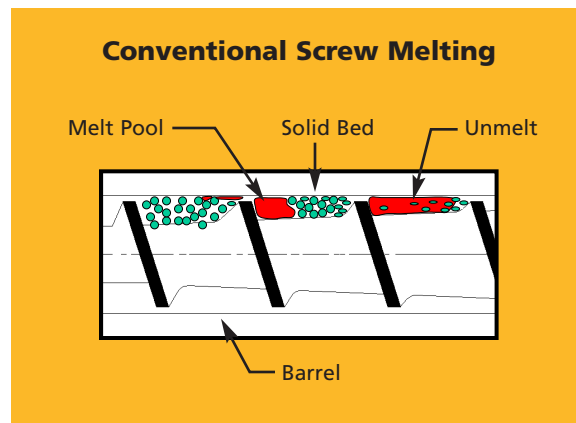


Figure 2. As shown, a conventional screw produces a melt-pool that eventually surrounds unmelted pellets, shielding them from the barrel wall where melting takes place.

greater the helix angle (or pitch) of the screw design, with all else being equal, the less shear you're putting into the material (because you'll have less flights over the length of the screw), and the greater the potential output rates (because of greater channel volume of the screw). Conversely, the smaller the helix angle, the more shear you'll have, and the smaller the potential output rates.

SPECIAL SCREW DESIGNS

Other than a conventional, single-flighted screw, in my opinion, there are two other important classes of screws. Both of these types of screws use secondary flights in their designs. The first type is a "barrier screw". This screw introduces a secondary flight, typically at the beginning of the melting or compression zone. The purpose of this flight is to act as a "barrier" between the melted and unmelted plastic. In a conventional screw (Figure 2), the melt pool can form an insulating layer around the unmelted plastic, keeping it from melting efficiently. A barrier screw (Figure 3) doesn't

allow this to happen, because the melt pool and the unmelted pellets are separated into two different channels. Therefore, the melting process is more controlled and efficient.

The second type of screw design often looks like a barrier screw, but is actually very different. This is a “distributive mix-melt (DMM)” design. In a DMM screw, there is a feeding zone, and a short compression or melting zone, similar to the compression zone on a conventional screw, but typically shorter. In this melting zone, approximately 60 to 80% of the plastic is melted. Then, a secondary flight is introduced in the “DMM” section of the screw (Figure 4). Several unique characteristics relating to that flight, and the corresponding channel depths in this section, make the DMM section’s function exactly opposite to that of the barrier screw. In this section, the melt pool is forced to mix with the unmelted plastic over and over again. In essence, the energy that has been put into creating that original melt pool is being re-used to finish the melting process. The result is a lower shear level imparted to achieve a completely melted product.

Obviously, screw manufacturers offer many different designs. However, these are usually variations of either a conventional or barrier screw with different types of mixers. The types of mixers often define the screw, however they are not contributing to the melting function. They are very important to the mixing function, and to ensuring a homogenous product. The number and types of mixers available are too many to go into detail here, however are important to a successful screw design.

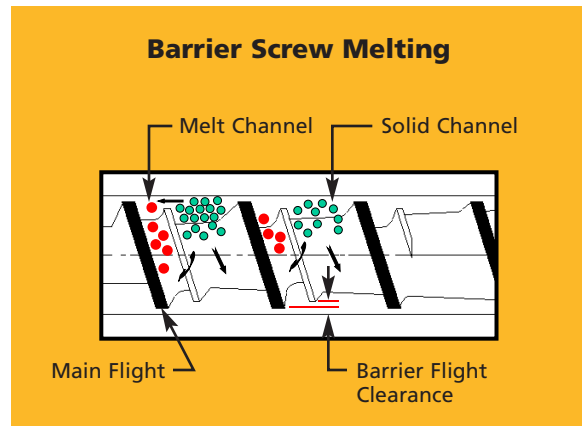


Figure 3. A barrier screw is very effective at keeping melt and unmelt separated until all resin is melted.

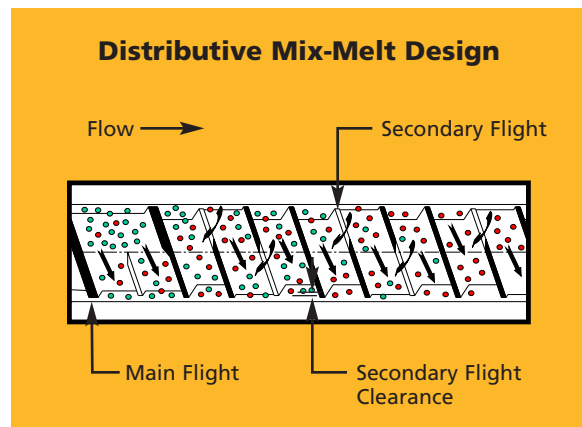


Figure 4. This distributive mix/melt screw design actually encourages mixing of melt and unmelt to achieve higher throughput rates and better mixing without the excessive shear that can occur with more aggressive mixing sections.

APPLYING DESIGN BASICS TO MEET OBJECTIVES

Now that we have reviewed various basic principles of screw design, let's consider how they can be applied in the real world to solve problems and to meet processing objectives. Let's look at a few more or less typical processing situations and consider what the "optimized" screw might look like.

Problem: "How can I maximize throughput of materials that are tolerant of heat- and shear?"

Solution: In extrusion or an injection-molding machine with 24:1 L/D barrel, the best approach would be to use a screw with both a barrier section and a distributive mix/melt section. A barrier gives you very efficient melting by separating melt and unmelt. Since you are processing shear-tolerant resins, you can put more shear and heat into the melt, so a barrier section will work effectively. However, on an injection screw, where overall length is limited, it may not be possible to make the barrier section long enough to achieve maximum throughput. A 20:1 L/D may not accommodate a barrier section at all. Even in extrusion, the barrier has limitations, because it eventually limits the screw volume and thus limits throughput. Adding a distributive mix/melt section after the barrier will complete the melting process without limiting volume. Its mixing action will also produce a more homogenous melt.

Problem: What if I'm processing shear-sensitive materials and mixing is critical?

Solution: There are two choices here. A screw that has a very gradual transition section and a distributive mix/melt section will melt shear-sensitive materials without

excessive shear, while the mix/melt section ensures complete melting and effective mixing, again without excessive shear. Option #2 would be a more or less conventional screw with a low shear mixing section uses changes in channel depth to compress and decompress the material, changing the flow of the material for good mixing without introducing shear.

Problem: What kind of screw is best for high-temperature materials?

Solution: High-temperature materials can be very different in the way they process, however you can typically use a screw with higher compression ratio, possibly including a barrier flight if output is critical and the material is shear tolerant. For those high-temperature resins that are also heat- and shear-sensitive it is a good idea to include chrome plating so that the resin is less likely to hang up and overheat and degrade. Unless there is a mixing requirement, a zero meter design (conventional feeding and transition sections but only one diameter of metering) so that once the material is melted, it is immediately discharged from the barrel.

Problem: Suppose you are running glass-reinforced materials and you need optimum melting, but don't want to break up the glass?

Solution: In most cases, the best option is to choose a mid-range compression ratio, conventionally flighted screw and invest in abrasion-resistant screw materials for longevity. This approach is usually better than seeking an elaborate (and more expensive) screw design.

Problem: I need to run three similar engineering resins and don't want to have to change screws.

Solution: Ideally you should look at the three different materials and determine what percentage of time you are going to be processing each and then develop a screw that does a better job of processing the resin you run most often. However, engineering resins are typically shear sensitive and can benefit from a distributive mix/melt design. The overall shear rate of this type of screw is lower than that of any other screw, and yet its melting and mixing characteristics are excellent. This makes it suitable processing a wide variety of materials. You can even use a high compression ratio transition section, to accommodate materials that need that geometry, while the distributive mix/melt section keeps the overall shear rate down.

CONCLUSION

Choosing the right screw for a particular application is not easy, and a screw design and manufacturing specialist is usually the most reliable resource for processors who need help making the right decisions. As we've noted, some applications can benefit from a more or less standard screw, but usually optimum results require a more customized solution. A knowledgeable screw designer can help you determine when a compromise that will maximize the flexibility of a given screw, and when you really need to optimize the screw design for optimum performance.



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