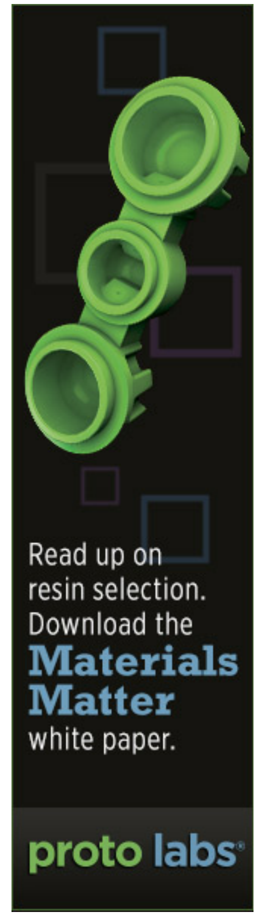
# Melt Pressure in Single-Screw Extrusion






By Alan Griff

**At the screw tip**

The melt is under some pressure at all places in the extruder, as that is what pushes it forward, but when we refer to melt pressure we usually mean the pressure at the screw tip. This is particularly important, as it relates to:

1. safety (too much pressure can blow the head off),
2. mixing (more pressure is good for mixing, especially in the metering zone),
3. melt temperature (more pressure = more work needed from motor = more frictional heat),
4. pumping rate (more pressure reduces pumping capacity (kg/rpm), varies with screw design)
5. thrust bearing wear (pressure is exerted backward into the bearing, shortens bearing life)

**Inside the extruder barrel**

1. a pressure peak may or may not be present: if the feed zone takes in more than the metering zone wants to pump out, there is a peak, typically at the entrance to the metering zone, and the pressure decreases from there to the screw tip. Otherwise, it continually increases from feed to screw tip. The presence of a pressure peak is signaled by an overriding of temperature control in the zone that controls the metering entry, an output equal or even greater than drag flow of the last flight, and a blue discoloration of the screw (the blue-screw syndrome).
2. a vented extruder always has a pressure peak in its first stage, as it feeds into a zero-pressure space (the vent zone) so the vent can operate properly. After the second stage, the melt pressure needs to be watched to prevent extrusion out of the vent; with most screw designs, a maximum of around 15-17 MPa can be reached before the screens must be changed or some other pressure-reducing action made.
3. screw beat is the once-per-rpm oscillation of the pressure as read at the screw tip, because the gauge is alternately measuring the pressure at the leading and trailing surfaces of the last flight. It can be quite large if the gradient of pressure (flight-to-flight change) across the metering section is large, or quite small if there is little such gradient. The gradient can go either way (rising or falling) but the direction is hard to see just from the screw beat. A better way is to look for the symptoms of blue-screw syndrome, as noted in a), and if that is present, there is a pressure peak and the gradient is falling.

Normally, screw beat does not affect the product, as it is absorbed by the elastic component of the melt as it passes through the head and die, but occasionally, with short and large dies, it has a pulsing effect on thickness. The usual effect of screw beat is to make pressure more difficult to read, and thus to discourage its use as a process variable.

**After the extruder barrel**

1. Pressure just after the screens will show the differential across the screen pack, which may assist in deciding when to change screens. Usually screens are changed when the pressure in the metering zone (as read at the screw tip) gets high enough to raise melt temperature to an unacceptable level, or else when output rate is reduced and cannot be regained by higher screw speed. Sometimes, screen changing depends on safety limitations (pressure has risen to an unsafe level). Also, there are screening devices that never need changing as they move a continuous strip of screen across the flow path. In such cases, the speed of screen motion may be controlled by the pressure on the entry side, or else on a time basis.
2. Pressure at the entry and exit of a gear pump are important: the entry is usually controlled to ensure that enough melt gets to the gear pump to keep it full. This control is achieved by changing the screw speed as needed to keep the pump entry pressure at the desired level (e.g., 5 MPa). The pressure at the pump outlet should be measured to ensure that the differential across the pump is not too great for its design. Otherwise, its ability to pump a constant volume is reduced.
3. Pressure inside a die is sometimes measured (but rarely). It is a direct reflection of the flow through the die, but is difficult to use as a control, because a small change in pressure means a larger change in flow, and pressure measurement must therefore be very precise to be meaningful.

**Reading and Measuring Pressure**

The first melt pressure gauges (ca. 1955) were open tubes filled with grease. These worked well enough to allow the first quantitative studies of extrusion by Maddock and others, but the grease often got into the product, and it lubricated parts of the die enough to cause flow problems. Closed gauges were then developed, using a thin metal diaphragm which pushed down on a column of grease or a push rod. This motion could be read directly or converted to an electrical signal by a transducer. Today's gauges still use this basic concept, but transmit the pressure through a thin tube of mercury to the transducer, located 1-2 m from the extruder head to eliminate its thermal effect on the signal. There are a few industries (e.g., medical tubing) where mercury gauges are not used because of the (small) chance of toxic contamination, and other fluids are used to transmit the pressure to the transducer. Still other sensing methods, including strain gauges and fiber-optics, have been tried, but have had limited success.

**Influences on Melt Pressure**

The melt pressure (at the screw tip) is the resistance of everything downstream of it: the screens and the contamination collected on them, the breaker plate supporting the screens, the adapter, the static mixer if there is one, and the die itself. Of these, the most important factors are usually the contamination on the screens and the die lip resistance. Sometimes, the internal design of he die is important, e.g., the spirals around the mandrel of a film die.

If there is a gear pump, it takes over the job of pumping through the mixer and die, so the pressure at the screw tip is just the resistance of the screens and contamination plus the pre-set entry pressure to the pump.

The screw design and operating conditions influence the melt pressure only indirectly, through their effect on temperature. Higher melt temperature means lower viscosity, which reduces the work needed to push the melt through the head and die, and thus reduces its resistance.

If screw speed is increased, more melt flows through the head, and resistance (i.e., melt pressure) increases. However, it isn't as much as might be expected from a standard fluid such as water, because of the shear-thinning effect of plastic melts: higher flow rate means lower viscosity even at the same temperature.

Resistance of the head, in terms of pressure drop, can be calculated rather easily from viscosity data and geometry. It is also possible to calculate resistance of clean screens, but this is not necessary if there is good measurement of melt pressure when new screens are put in. Even when a finer screen pack is being used to raise pressure (usually to improve mixing), calculation is relatively unimportant, as the resistance of clean screens is comparatively low compared to the contamination that they collect.

In a few cases, an extruder may use no screens, and all the pressure at the screw tip will come from the resistance of the adapter and die. This is typically for UPVC, where the processor is worried about increased melt temperature encouraging degradation, and is risking the chance of contaminating the product in order to get the advantage of a cheaper formulation (less stabilizer) that can be used because of lower temperature.

The size of the extruder itself has no influence on melt pressure, except as it may influence throughput. As with increased rpm, if more material is pushed through the same screens/head/die, the pressure will be higher.

**Reasonable Operating Pressures**

This depends very much on the product being extruded. Most commercial extruders can take at least 100 MPa within the barrel and at least 60 MPa at the head, but the machine maker should provide such limits as part of the equipment specification. The higher barrel limit is needed because of the possibility of a pressure peak, as noted above. In practice, there is little danger of bursting a barrel, as the steel typically used is ductile enough to expand and even creep at high pressure: clearances to the screw are increased and production reduced, and the cause of the high pressure thus relieved.

The barrel liner, typically a hard alloy about 1.5 mm thick, is less ductile, and may show longitudinal cracks if held under high pressure for a long period of time. Sometimes this can be seen by visual inspection. It may not matter if production per rpm is not materially reduced. This variable must be continually measured to monitor wear and expansion of the screw-barrel combination. If production per rpm doesn't fall much, the wear and expansion make little difference and can often be ignored.

In real production, the melt pressure (resistance) depends very much on the resins used and especially the product to be made (die design and lip opening). Very viscous resins like ABS, UPVC and fractional-melt HDPE, will yield higher pressures than the less viscous ones like polystyrene, PET, PP and some LDPE. Linear-low-density PE is unique in that it shows less shear-thinning effect and thus generates more frictional heat and higher pressures than regular LDPE.

As for product effects, large areas, like rods, heavy sheet and multi-hole compounding dies, offer relatively low resistance, and melt pressures with clean screens may be as low as 6-10 MPa at the screw tip. Smaller profiles and thinner sheet are typically 10-25 MPa, and small wire insulation may be as high as 50 MPa or more. Film dies, with their spiral pathways used to get uniform thickness, may run 25-40 MPa, and because melt temperature so often controls production rate, there must be a compromise made between uniform film thickness and pressure. A lower-pressure die may allow faster production, but if its thickness is not as uniform, there will be material wasted (too thick) or failure risked (too thin).

Apart from screw beat, which is explained above, pressure should vary very little -- +/- 1% in the head is a lot, but is commonly seen. The usual sensor-display combinations cannot show finer differences, and very few lines have the high-cost gauges that could read more closely (i.e., less that 10 psi = 0.07 MPa).
Pressure is a dependent variable, and is almost never controlled, except with gear pumps, where screw speed is changed to make sure the pump doesn't starve (its bearings are melt-lubricated). Also, with vented extruders, a valve is occasionally seen after the screens, to make sure that as much of the second stage is full as possible, but not so much as to cause extrusion out of the vent.

The most common way of "controlling" pressure is to change screens – use a finer or coarser screen pack. This is really letting the contamination do the controlling, and has the inherent disadvantage of being unstable – as contamination increases, so does pressure. Nevertheless, it is an inexpensive, reversible and sometimes quick way to get the balance of mixing and melt temperature that may be required.

**Effect of Melt Pressure on Product Properties**

This effect is indirect, as the melt doesn't "remember" its pressure after it leaves the die. However, as pressure affects mixing and melt temperature, these things may affect product properties: insufficient mixing may affect appearance (streaks, lumpy surface, product weakness), and excessive temperature may lead to product degradation or cooling/sizing problems.

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