Two stage extrusion

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Bob Gregory submitted the following question and answer to an extrusion problem. As Bob pointed out in the last Newsletters the questions have run out—the well is dry!

If we don't get participation from the readership then this facet of the Consultants Corner will just fade away. We need your help to keep this going—if you want it.

— Ed.

Question:

In a two stage extruder we have barrel cooling on the 10 L/D second stage. With everything else constant, if we drop the barrel temperature from, for example, 300° F. to 2002+/-1F, the pressure development of the second stage drops drastically—perhaps 30% or more. With a full second stage, I am defining pressure development as the gain over the 10 L/D.

Simulations and intuition predicts a higher pressure development because of colder, higher viscosity melt, even allowing for poor mixing. But that is not what we see. A reduction in land clearance due to thermal contraction could cause excessive shear heat. Simulations confirm this if one uses extremes.

- C.L. Woodworth, Monsanto Plastics and Resins Co.

Answer:

In the situation described, I would agree that the normal expectation would be for a greater capability of pressure development with lower barrel temperatures, rather than a lesser as has been actually experienced and measured. We will assume that the discharge pressure at the end of the screw is approximately the same under both operating conditions. With the same head pressure at the tip of the screw in both situations, a lesser ability to generate pressure would result in a higher pressure being read at a gage 10 D upstream from the end of the screw. With the lower barrel temperature and greater cooling effect, the polymer temperature would be lowered, the viscosity increased, and the pressure generating ability increased, this would be the expected result from the given data, but this is not what actually occurs. Since the available data does not include any information sufficient to offer an explanation for the observed results, it is possible only to speculate on certain conditions that would explain what has been observed.

The experience of seeing decreasing pressure generating ability with lowering of barrel temperatures for greater cooling is unusual but not unknown. In the present example there are two possibilities that would offer a fairly direct explanation. Although screw cooling is not mentioned, it may be that this is used in the process and, if it is used, it would in some situations bring about the observed phenomenon. When the root of the screw is cooled internally the result is to have a cooling effect on the polymer and, in addition, an effect is produced of increasing the viscosity of the material close to the surface of the screw root. In the case of severe cooling, at temperatures below the melting point of the polymer, material will actually set up on the screw root for a certain thickness and in addition there will be a higher viscosity layer adjacent to the material frozen to the screw. This results in an effect similar to a change in the screw geometry equivalent to a shallowing of the screw channel which brings about the decrease in the rate capability of the screw and can thus have an effect on the pressure generating capability of the screw. This channel shallowing effect resulting from greater screw cooling car have a tendency to decrease pressure at a given rate rather than increase it. This is most likely to be noticeable when pumping at high throughput efficiencies: i.e., the throughput rate is rather close to the open discharge rate, say in the range of 90%.

This refers to an open discharge rate as being the pumping rate capability of the screw when it is completely filled with polymer but is not generating any pressure, also referred to as the drag flow rate. When a restriction is offered by a die or other means at the discharge end, the throughput rate goes down and the pressure generated goes up. For example, one might find that at 90% of open discharge rate a give screw will generate 2000 PSI, and at 80% of open discharge rate it will generate something less than 4000 PSI. Of course, the polymer temperature will also be effected, and the temperature rise through the extruder will be greater when extrusion conveying efficiencies are low, rates are low, and pressure generation is high. At lower pumping efficiencies, say in the range of 75% to 80% of open discharge rate, the effect of channel shallowing due to screw cooling is usually less noticeable and is overshadowed by the effect of polymer cooling that results in higher polymer viscosity and thus greater pressure generation.

By way of analyzing this problem, a hypothetical extrusion process was set up for computer calculation. A Typical high viscosity PVC material was used for the polymer. The geometry of the second stage of the extruder in this example was simulated by a 10" extruder having an 18:1 L/D with pressure generation being confined to the last 1OD of the screw which was the metering section with a channel depth of .600". A calculation was made with cooling in the screw at the same temperature as the barrel cooling, first, at a temperature of 300°, and then at a temperature of 200° F, to result in a calculation of comparative performance. Using a constant entry temperature of 340°F and a constant RPM and rate, with cooling temperatures set at 300° F, the calculation showed a head pressure of 2820 PSI and a product discharge temperature of 424° F. When external temperature controls were reduced to 200°F, the discharge pressure dropped to 2116 PSI even through the polymer temperature coming out of the machine had decreased to 411°F. The lower discharge temperature indicated a significant increase in polymer viscosity, but nevertheless the channel shallowing effect was sufficient to decrease the exit pressure. The calculation was continued to show the needed increase in screw speed to return to the original pressure and it was required to raise the speed from 38 RPM to almost 51 RPM.

The other possible internal cause is the slipping of the molten polymer across the surface of the bore. This is a phenomenon that has been seen previously on large melt fed extruders. A similarity of performance with a melt fed extruder is valid because the second stage of the extruder in the example is similar from a process standpoint to a melt fed extruder. In some situations a higher temperature on the barrel, particularly toward the feed end, has been used to get much better pumping and pressure generation. PVC types of materials can exhibit this characteristic. Unfortunately, there is very little quantitative date on this phenomenon. One would speculate that the slippage occurs when the metal is cooler than the polymer, and it is very possible that when the metal temperature is below the melting temperature of the polymer, the effect would be more extreme.

There are some references of experimental work done. Most of the work has been on friction coefficients with solid polymers across metal surfaces, and it is possible that some similar effects can be true with molten polymers, particularly in the low temperature range. I would cite two references that might be of interest:

"Processes in the Feeding Zone of an extruder", published by the Institute of Plastics Processing, Aachen, August 1969.

"Friction Coefficients of Plastics and Steel", by Robert B. Gregory. SPE ANTEC. May 1969.

The performance of the process with slippage on the surface of the bore was also simulated in a computer calculation. A normal performance was compared to performance when there was slippage on the bore surface. When this slippage was such as to reduce the open discharge rate capability to 95% of normal, the discharge pressure decreased by 9%. When a more extreme case was considered, where the slippage was such that the open discharge rate capability was reduced to 90% of normal, the discharge pressure dropped by 37%. In these three cases, (normal, 95% of normal, and 90%), all input conditions were the same except for the slippage.

Thus we see two possible explanations for the unusual results observed. With additional data, it might be possible to determine that one or both of these effects are actually operating in this machine, or that perhaps some other less obvious effect is producing those results.

- L.F. Street, Extruder Design Co., Washington, N.J.

See also

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