Extrusion Technology - Some New Findings

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In diagnosing extrusion problems and in the design of extruder screws most people use simplified equations derived for Newtonian melts. Some highly advanced engineers get more involved utilizing non-Newtonian techniques and a few even consider the effect of screw geometry and operating conditions on the melting process. Almost everybody totally disregards solids conveying. Since solids conveying is very often the limiting step in an extruder, the performance of an extruder can seldom be improved without studying this zone.

Solids conveying The earliest mathematical analysis of the solids conveying zone revealed the relationship between the ratio P out/P in that is the ratio of the outlet and inlet pressures of the solids conveying zone and the production rate in various screw geometries. This relationship, however, failed to reveal the mechanism which governs the performance of the solids conveying zone.

Only after the effect of the friction coefficient and hopper geometry on inlet pressure was clarified could the mechanism of solids conveying be understood.

It became clear that for an extruder to perform properly the solids conveying zone must develop adequate pressure to compact the solid bed. If the solid bed is not sufficiently compacted this seemingly insignificant matter has an adverse effect on the performance of the whole extruder. As soon as melt starts to form on the barrel surface instead of forming a melt film, it penetrates the voids of the loosely packed solid bed. As a result of replacing air with plastic melt the density of the solid bed increases, its volume decreases and contact between the solid bed, barrel and screw surface is at least partially lost. Without an intimate contact with the surfaces the plastic is no longer sheared and melting stops until the channel backfills from the die or contact is resumed in the compression season. Besides the loss of melting action over a considerable length of the extruder, this semi-filled portion of the screw cannot raise pressure and consequently a lower output results.

Inadequate solids conveying also greatly lowers the melting and pressure building capacity of an extruder.

Non-Isothermal Solids Conveying The solids conveying theory reveals that lengthening the solids conveying zone always improves solids conveying. This implies that cooling a longer portion of the barrel in the vicinity of the hopper will always eliminate solids conveying problems.

This reasoning did not prove correct in every case. The discrepancy was explained by the non-isothermal solids conveying theory. The rubbing of the solid bed against the barrel generates heat which will somewhat raise the temperature of the solid bed and heat up the cooling water. The largest effect usually is on the surface temperature of solid plastic in contact with the barrel. This temperature can even exceed the melting point of the plastic and thereby terminate the solids conveying zone despite any cooling that may be applied.

The non-isothermal solids conveying theory explains the phenomenon of heating the barrel surface in the solids conveying zone of an extruder by frictional force. It even explains that the potential pressure rise in the solids conveying zone is limited precisely because of this temperature rise. This is so because the higher the pressure gets the higher the heat generation which shortens the extruder length required for the resin pellets to reach the melting point. The temperature rise therefore prevents an excessive pressure rise.

However, the normal solids conveying problems occur at the low pressure end when solids conveying is inadequate. Since under these conditions heat generation in the solids conveying zone is insignificant, the non isothermal solids conveying theory can not explain these problems. One has to examine the frictional properties of the resin closely.

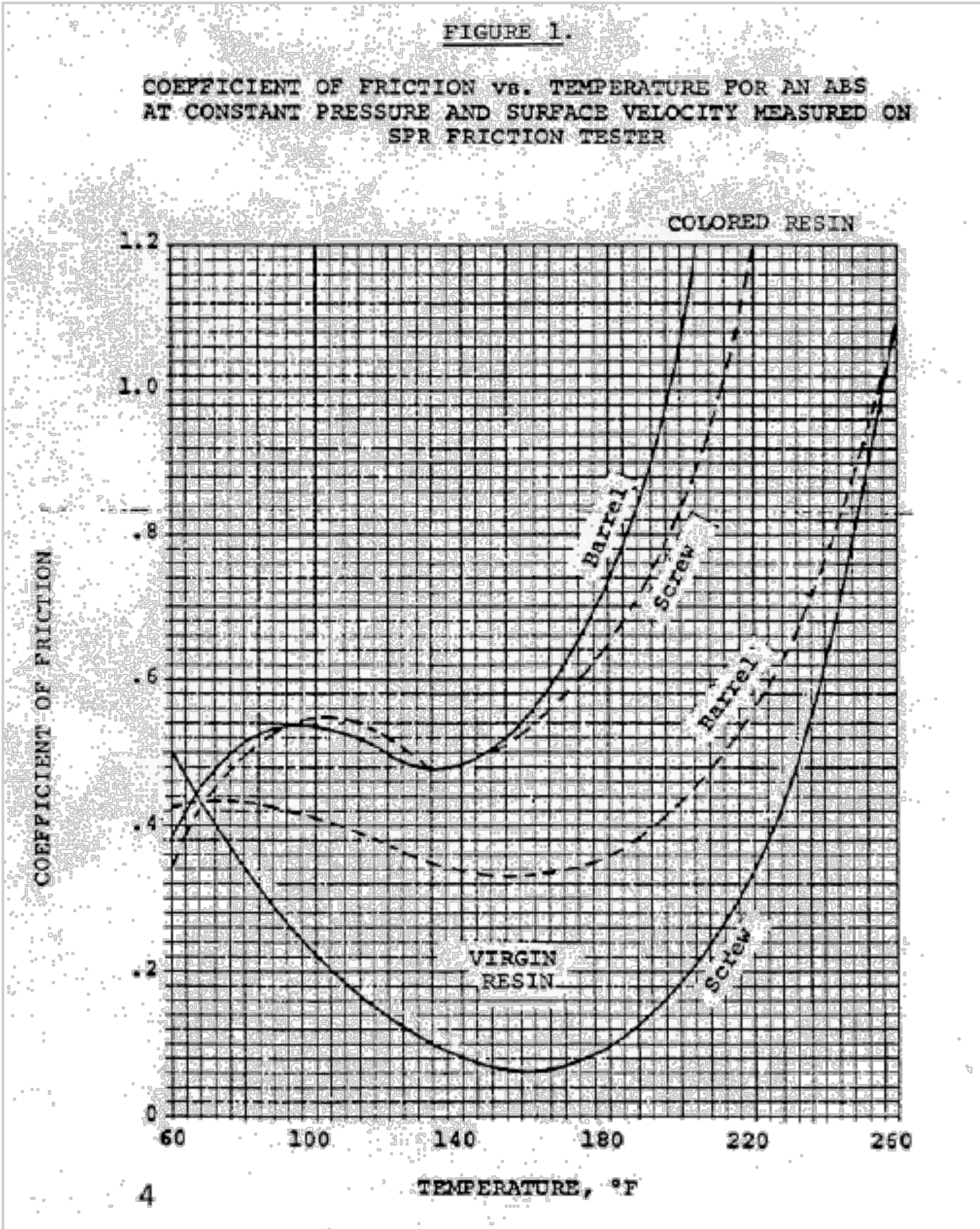

Figure 1

Frictional Properties of Solid Plastics It was found the coefficient of friction of a plastic is not constant but is greatly affected by surface temperature, pressure and surface velocity. Since the surface velocity of the barrel is high and that of the screw is low relative to the solid bed, some resins exhibit a higher coefficient of friction on the barrel surface than on the screw. Such a differential of frictional properties on the two surfaces is a prerequisite to insure proper solids conveying. This is the case for the virgin ABS shown in Figure 1. As can be seen over most of the temperature range the coefficient of friction on the barrel surface is considerably higher than on the screw surface.

Adding a small amount of color concentrate or of other minor ingredients eliminates this differential and can therefore totally destroy the extrudability of the plastic.

The differential in the coefficient of friction on the two surfaces can sometimes be reestablished by artificially maintaining a temperature differential between the barrel and screw surfaces in the solids conveying zone as seen in Figure 1.

As solids conveying is improved pressure rises. Very often the coefficient of friction drops with pressure rise and causes deterioration in solids conveying. Instead of the pressure rising exponentially with axial location which would be the case with constant coefficients of friction, it switches from an exponential to a very gradual pressure rise. In many cases due to the degradation in frictional properties caused by elevated pressures, further pressure rise is totally discontinued after an initially rapid rise. This renders the lengthening of the cooled hopper zone ineffective in attempting to improve solids conveying in an extruder at certain temperatures and screw speeds.

- Imrich Klein

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