

Table 1
Polymer Properties

Feed - Size & shape
Uniformity
C.O.F. External
C.O.F. Internal
Yield Strength
Polymer -
Melting point
Heat capacity
Thermal conductivity
Viscosity
Elasticity
Shear sensitivity
Temperature sensitivity
Thermo-mech. stability
Melt density
Additives

Table 2
Operation Variables

Feed regulation
Screw speed
Temperature set points
Screen pack selection
Back pressure level

Table 3
System properties

Power / torque
Length / diameter
Temperature control
Screw design
Mixer design
Screen changer design
Back pressure valve design*
Melt pump design*
Pipes - length / diameter
Stationary mixer design
Co extrusion adapter design
Die manifold design
Die shape adjustment

* where applicable

The structure of the polymer will dictate the polymer properties. The metallocene catalyst technology allows tailoring of the polymer structure to obtain specific finished product properties. The primary structural elements considered are:

1. molecular weight (MW)
2. molecular weight distribution (MWD)
3. long chain branching (LCB)
4. short chain branching (SCB)
5. and comonomer type and amount.

Adjusting these structural elements of the polymer also affects processing. Increasing the MW while improving toughness causes the polymer to be more viscous during processing yielding higher processing temperatures. A narrow MWD improves strength properties but again reduces shear thinning yielding higher processing temperatures. A broad MWD will provide higher melt strength and improved optical properties. A high level of SCB will reduce crystallinity and stiffness providing toughness, good optics, and increased permeability. LCB will increase melt elasticity and surface haze and reduce gloss. The power of the metallocene technology is it allows one to build on this combination of properties as required. The next step is to review how these polymer property characteristics interact with the equipment design.

Equipment design considerations

We can separate the equipment into three basic areas for the purpose of this design discussion, the extruder, the transport system, and the forming system. The key elements in the extruder being the drive system, the feedscrew with mixer, and the temperature control system. The transport system would include all elements in the flow path between the extruder and the forming system. This could include screen changer, back pressure valve, transfer pipes, stationary mixer, and metering pump. The forming system may include the co extrusion combining adapter and the forming die. In most instances the new polymers will be introduced to enhance the performance of an existing product and will be processed on existing equipment.

It is recommended by both the commercial suppliers of metallocene resins to process on equipment intended for processing linear low density resins. From the previous discussion on material properties it is apparent as you target higher MW and narrow MWD and reduced SCB the material will become more difficult to process. Due to the higher crystallinity, higher viscosity, and reduced shear thinning it will require more energy. On existing equipment this translates into more horsepower or higher torque with higher processing temperatures and operating pressures. It is not unusual to see an increased power requirement as high as 25%. If this drive power is not available the options are to increase the drive motor horsepower or re gear to a lower screw speed. Care should be taken to maintain an adequate service factor on both the gear box and the screw root.

The extrusion feedscrew and mixer design will control the melt quality during processing. It is impossible to have a single feedscrew design that is optimized for all the resins it may potentially run. For this reason it is most important to consider all current and potential materials that will be run on the screw and the amount of time they will be run. If the new resins are only a small part of the product mix to be run on a particular machine more compromise on the performance on that resin can be expected. Some of the short comings of a particular screw design may be offset by the operating conditions such as an inverted temperature profile to reduce drive amps and keep the temperature low. Again both the commercial suppliers of metallocene polyethylenes recommends the use of a barrier screw design. Typically barrier screw designs achieve higher melting efficiencies with lower shear energy input. As the energy input to the melt is a linear function of the materials viscosity a material that exhibits reduced shear thinning will gain more energy during processing. This material will also develop more pressure in the screw, transport system, and die. The higher system pressure means increased residence time in the screw contributing to yet higher temperatures. When a variety of materials are run a back pressure valve may be used to improve the performance of a deep screw on less viscous materials by increasing the effective shear rates and residence times. If a particular machine will be dedicated to running one material an optimized screw design can be developed.

It is important to discuss mixing in regards to screw design. Current state of the art screw designs incorporate a mixing element. Typically this will allow increased outputs with improved quality. These mixing devices will breakdown through shear input (disperse) additives or unmelt or systematically rearrange (distribute) the flow stream to improve melt homogeneity and temperature uniformity. Some mixing devices serve both functions. A long barrier in a screw design is a form of dispersive mixer. When processing at it's design point no additional dispersive mixing should be required. This is significant as inclusion of a second high shear mixer will consume more energy and may tend to overheat the polymer. In addition, many high shear mixers create a considerable pressure drop. This can create a potentially dangerous situation as most production extruders only have pressure indication downstream of the mixer. Actual operating pressures in the extruder may be 1-2 thousand psi higher than indicated by the pressure transducer with a poor pumping high shear mixer. An optimized mixer design then for metallocene resins should have low to moderate shear, provide forward conveying to reduce pressure losses, and create multiple flow re arrangements.

The transfer system and the forming system each provide resistance to the polymer flow. The extruder and feedscrew must generate the pressure to overcome this resistance at the flow rate desired. Changing to a metallocene resin will generally increase the operating pressure of the system. Typically 1/3 or more of the system pressure drop occurs in the final forming lands of the die. High resistance also occurs in the screen changer and back pressure valve. Changes through the transfer system that will improve the pressure performance include increase the screening area, increase pipe diameters, increase valve clearances, and reduce transport pipe lengths and turns. Note that these first three actions will also each increase the average residence time in the system.

The forming system offers the greatest opportunity to reduce the overall system pressure. Increasing the final die opening is frequently possible by a simple die adjustment. In other cases it maybe accomplished through minor modifications to the die. A die replacement is a simple if somewhat costly procedure.

Summary

A new family of metallocene catalyzed polymers has been introduced offering improved performance properties. When targeting increased MW, narrow MWD, and reduced SCB these polymers will be more difficult to process. Increased extruder torque, low shear screw designs to keep melt temperatures down, as well as low pressure transport and forming systems will be required for optimum processing. Many existing systems will be adequate for limited processing at reduced outputs and using operation special operating techniques to keep temperatures and pressures down. Particular attention should be given to mixing devices to enhance performance and protect from excessive pressures.

Acknowledgments

I would like to thank Dr. Harry Mavridas at Black Clawson-SANO for his assistance and background information. Also Dow and Exxon for their assistance with technical literature and materials for laboratory trials.