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Polyolefin Flow Characteristics: More than Just Melt Index or Melt Flow Rate

INTRODUCTION

Somewhere along the way, all polypropylene (PP) and polyethylene (PE) resins must be melted in order to be formed into their intended shapes whether it is filament, film or molded articles. Consequently, flow properties are important product characteristics that affect not only processability but physical properties as well.

Melt Flow Rate (MFR) is a value obtained when a product is tested on an extrusion plastometer. Melt Index (MI) relates only to polyethylene in its determination of melt flow rate. MFR and MI provide a measure of the amount (in grams) of material that flows through an orifice of a specified size in a specified length of time (10 minutes). The procedure is described in ASTM D 1238. The higher the measured quantity, the easier the material flows under a given temperature and pressure. This index is inversely related to the viscosity (resistance to flow) and the average molecular weight of the material. In other words, the higher the viscosity or molecular weight, the lower the MFR or MI.

For many liquids, like water, viscosity stays relatively constant no matter how hard or fast the fluid gets pushed through an orifice. These liquids are called "Newtonian Fluids." Thermoplastics are "non-Newtonian Fluids" because their viscosity changes depending on the speed (shear rate) at which the pressure or force causes them to flow (see Figure 1). As the speed (shear rate) increases, the viscosity of non-Newtonian fluids decreases.

RHEOLOGY

Rheology is the science of flow, and sophisticated instruments called rheometers are used to determine the flow behavior or viscosity of thermoplastic resins at the high shear rates used in most processing methods. The shear rate used to determine a resin's MFR or MI by the ASTM test method is very low by comparison and does not provide a complete picture of the material's flow behavior. Sometimes rheology testing is performed at different temperatures to determine the temperature sensitivity of a particular PP or PE resin (see Figure 2). Different PP or PE resins may have different sensitivities because of the reactor technology or catalyst used to produce them.

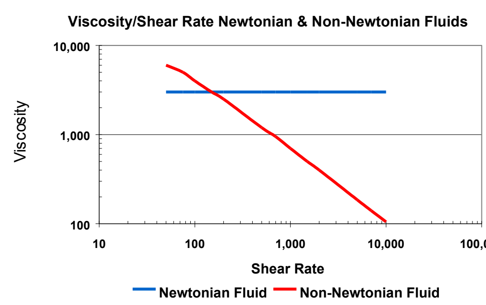

Figure 1: ***Newtonian simple shear rate/viscosity curves vs. non-Newtonian ones***

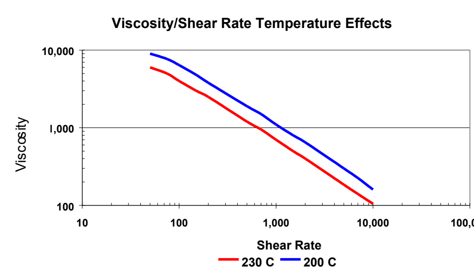

Figure 2: Simple shear rate/viscosity curves at three different temperatures

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Just as important as temperature sensitivity is shear sensitivity noted above, the viscosity of a non-Newtonian fluid, such as PP or PE, goes down at higher shear rates (see Figure 3). This fact makes injecting these resins through small nozzle tips or extruding them through tiny spinnerets practical. Like temperature sensitivity, shear sensitivity is also affected by production process or catalyst.

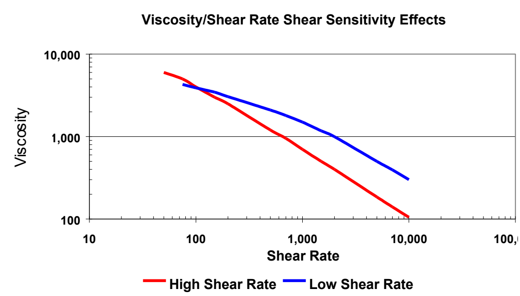

Figure 3: ***Simple shear rate/viscosity curves at two different shear sensitivities***

The differences in shear sensitivity and temperature sensitivity of PP and PE resins exist because of a characteristic of these materials known as “molecular weight distribution” (MWD). When produced under commercial production conditions, these resins cannot be made in a single molecular weight. Actually, each grade of PP or PE resin contains polymer chains with a very wide distribution of molecular weights. The relative differences in the “spread” of molecular weights in grades separates them into the categories of "narrow MWD” (NMWD) or "broad MWD" (BMWD) products (see Figure 4). A PP or PE grade can also be manufactured as NMWD or BMWD product by varying certain conditions in the production process or the catalyst used. As a result, two products can have the same MFR or MI and the same average molecular weight but have significant differences in their MWD and physical properties. All things being equal, a broad MWD product is more shear sensitive than a corresponding narrow MWD product (see Figure 5).

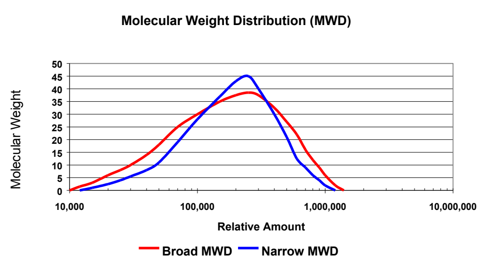

Figure 4: ***Single GPC curves for BMWD vs. NMWD***

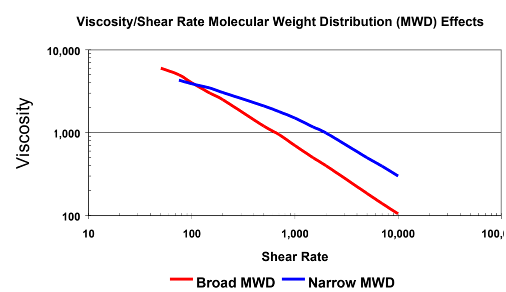

Figure 5: ***Simple shear rate/viscosity curves for BMWD vs. NMWD***

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EFFECT OF VISCOSITY ON PROCESSING

Products with lower viscosities at processing shear rates, whether derived from lower average molecular weight or broader MWD (more shear sensitivity), flow easier, require less pressure (and energy) to extrude and have fewer molded-in stresses.

Materials with high viscosities or broad MWD are useful in processes such as extrusion blow molding, blown film, profile extrusions, etc., where an extrudate must be somewhat self supporting before solidifying, requiring a material with enough melt strength to prevent collapse. A high viscosity resin at low shear rates is a definite advantage in these cases. Ideally, a broad MWD is advantageous so the viscosity is low in the high shear portions of the process, i.e., at the screw and die. A high molecular weight product also tends to exhibit greater toughness and chemical resistance.

A narrow MWD is advantageous in some fiber and molding applications. Since an NMWD material contains polymer chains with more uniform molecular weights, the response of this material to internal stresses (due to flow or cooling) and external stresses (stretching) is much more uniform than with a BMWD product. This uniformity results in better drawdown characteristics for fiber production, including much higher elongation at break properties and less warpage. NMWD products also exhibit more uniform shrinkage when they are used for injection molding.

CONCLUSIONS

Although the relative flow properties of PP and PE resins can be described by the MFR or MI, this fairly simple index represents only a small part of the product's total flow properties. To understand fully how a product processes and performs in its intended use, it is often necessary to know the full rheological behavior of the resin. This information is also important when products from different sources or even different grades of material from the same source are compared.

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