GE Plastics

Sharing The Knowledge
Module 8

Flowing and Forming Polymers

M-PLA-0117-STK-MOD 8-12/89-00-1

STK 801

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Module 8

Flowing and Forming Polymers

- Understanding Flow of Plastics
  - Melt Flow Rate
  - Melt Viscosity
  - Shear Rate
  - Temperature Effects
  - Thermal Stability
- Thermoplastic Processing

8

Participant's Notes: ______________________________

STK 802

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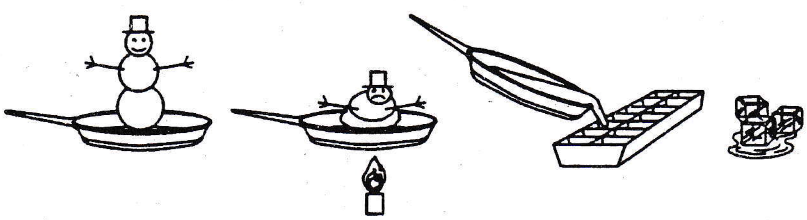
Flowing and Forming



When a solid is melted, it can be reshaped and cooled into a different shape.

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Introduction

An understanding of flow behavior is essential to good processing.

Flowing and Forming Polymers

Throughout Sharing the Knowledge, we've differentiated polymers according to their property and processing characteristics. Property performance is reported for a material in its solid state, as that is how it's likely to be used in application. But as we've seen, materials also respond differently to processing. Each material has its own flow behavior and therefore its own specific processing characteristics. It is important to understand how a material flows. This module examines the flowing and forming of polymers and the important variables that hinder and improve the process. **STK 801**

Objectives:

At the end of this module, participant should be able to:

- Describe why rheology is fundamental to processing.
- Differentiate melt flow rate from melt viscosity.
- Describe how temperature and shear rate affect viscosity.
- Describe how shear can cause degradation in a polymer.
- Relate the processing window to the flow limitations of the polymer.
- Describe two processes which limit thermal stability in a polymer.
- Relate five different uses for rheology.
- Describe how the processor can affect the quality of his parts through using his knowledge of rheology.

In order to reshape a solid, it should be melted and reformed.

What Is Flow?

We all know that water, in its liquid state, is able to flow. Similarly, all liquids are able to flow. Flow means nothing more than the ability to move as a liquid does. When water is frozen into ice, it does not flow, but acts as a solid. However, upon heating the ice returns to its liquid state and is able to flow. In its liquid state, water can easily take on the form of its container, and with sufficient cooling, it will freeze into that form. The processes of thawing and freezing water are merely an example of physical transitions in states of matter.

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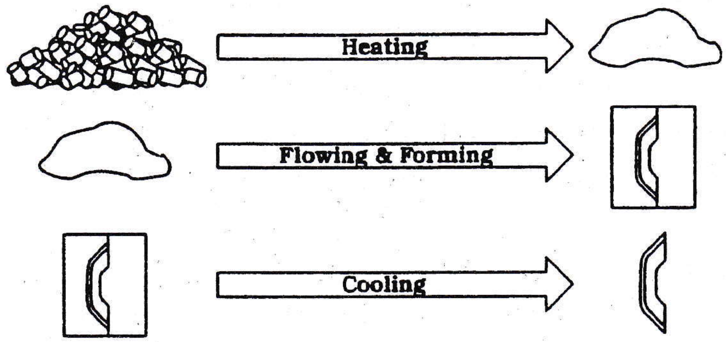
Thermoplastic Processing



During processing, thermoplastics are heated until they flow, formed into a part, and cooled until they harden.

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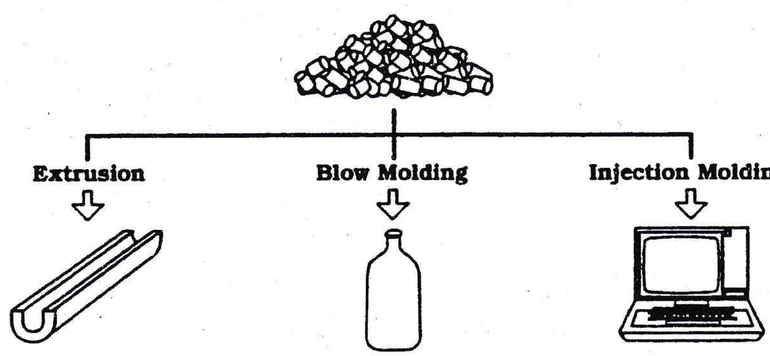
Conversion Processes



In any conversion process, the polymer melt is shaped into a finished part.

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Participant's Notes:

Thermoplastic Processing

Thermoplastic processing consists of melting, flowing, forming, and cooling.

Engineering Thermoplastics also go through a physical transition upon heating, changing from a solid to a fluid. In its melt state, a thermoplastic is able to flow. The conversion process involves taking the thermoplastic into its melt state, forcing it under pressure into a desired form, then cooling the thermoplastic to obtain a solid useful part. **STK 803**

Conversion Processes

Thermoplastic conversion processes differ by the methods used to soften and form the plastic.

There are many processes of converting plastics into usable parts. Still, in each conversion method, the plastic must first be softened, then formed. The ability of plastics to soften when heated, form into a shape when molded, and solidify into a part when cooled is what makes them unique. Conversion processes vary only by the combination of methods used to soften the material and to form it into the finished part.

Once a plastic is melted, pressure can be applied in a variety of ways - by squeezing, by pressing, by stamping, by injecting, by extruding, or even by inflating the plastic so it forms to the contours of the mold or die. The method used to mold the material depends on the process of conversion. **STK 804**

STK 805

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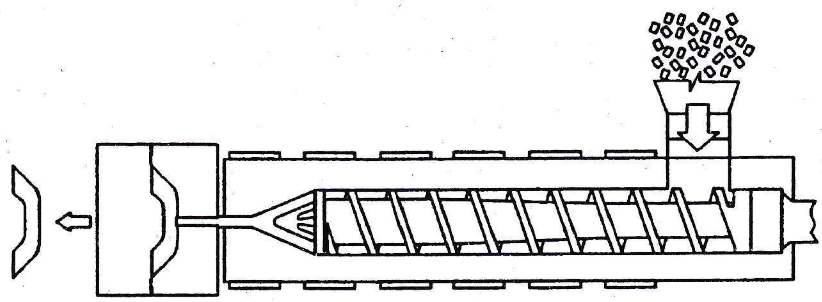
Flowing & Forming



In injection molding, the polymer melt $\boxed{\text{flows}}$ through the screw, the nozzle, the sprue, the runners, and is $\boxed{\text{formed}}$ in the cavity.

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Participant's Notes:

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Flowing and Forming Polymers

- Understanding Flow of Plastics (Rheology)
- Thermoplastic Processing

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Participant's Notes:

Processing consists of adding heat to melt the pellets and applying pressure to shape the part.

Flowing and Forming

To soften a thermoplastic material, energy must be applied to heat it and raise its temperature. This heat energy is usually generated either electrically or mechanically, or by a combination of the two. The method used to raise the temperature of the material to make it flow depends on the process of conversion. Once the material is flowing, pressure can be applied to form it into a part. **STK 805**

Understanding rheology leads to an understanding of processing.

Flowing and Forming Polymers

First let's discuss the science of polymer flow, rheology; then we'll discuss how this understanding of flow is useful in the processing of high quality parts. **STK 806**

STK 807

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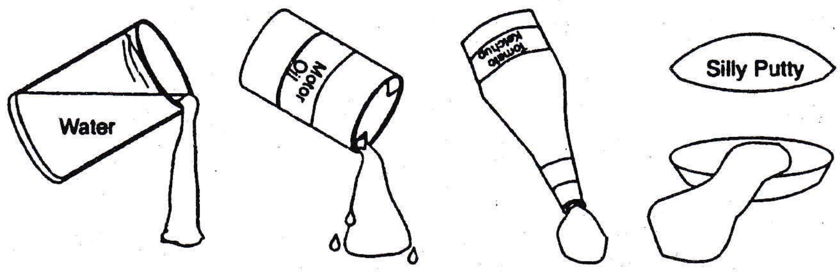
The Study of Flow



The study of deformation and flow is called **Rheology.**

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Rheology

"Single Condition" Measurements

- Melt Flow Rate
- Melt Viscosity

Rheology in Processing

- Shear Rate Effects
- Temperature Effects
- Time Effects

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Participant's Notes: ______________________________

Rheology is the study of deformation and flow.

The Study of Flow

Polymer rheology is the study of the deformation of a material in its fluid state. Just as different solids have varying abilities to resist deformation, so do different fluids. Water has less resistance to flow than motor oil, which has less resistance than ketchup, which has less resistance than Silly Putty™. Rheology is the study of material deformation and flow. **STK 807**

Rheology may be either a "single condition" QC test or a full processing characterization.

Rheology

Rheology is used in many ways. First, we will look at a simple characterization of polymer flow through tests that measure a single point in the continuum of flow. These "single condition" tests are useful in Quality Control (QC) of a polymer's flow.

Later, we will see how to completely characterize a polymer melt through understanding how the melt changes under conditions of changing shear, temperature, and time. These types of rheology studies are used for predicting a polymer's response to the varying conditions actually seen in conversion equipment. By understanding the polymer's complete rheology response, we can predict how it will act in any conversion process. **STK 808**

STK 809

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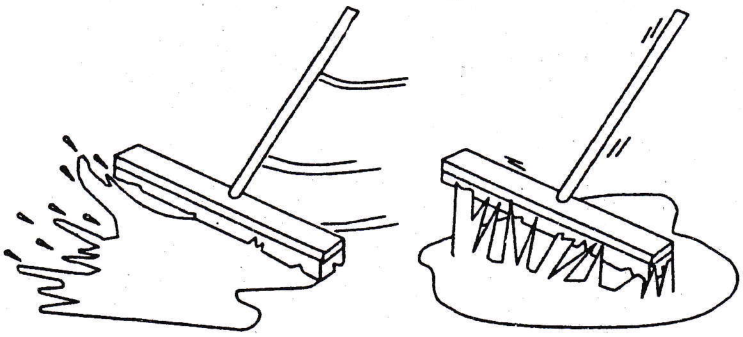
Viscosity



Low Viscosity High Viscosity

Measures a materials resistance to flow.

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Measuring Viscosity

Any Measure of Viscosity Depends on Three Variables:

- Rate at Which the Melt Is Moving
- Temperature of the Melt
- Geometry Through Which the Melt Passes

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Participant's Notes:

Viscosity

Viscosity is the measure of a material's resistance to flow.

Viscosity is a measure of a polymer's resistance to flow. Materials such as water offer little resistance to flow and are said to have a low viscosity. Materials such as motor oil, which offer more resistance to flow are said to have higher viscosities. **STK 809**

Measuring Viscosity

The three variables which control viscosity are the temperature of the melt, the geometry through which it moves, and its rate of motion.

Each polymer has a measurable resistance to flow. This viscosity will change as the temperature of the material changes. The viscosity also depends on the rate at which the polymer is moving, and the geometry through which the polymer is flowing. Rate, temperature, and geometry are the three important variables to consider when making a measure of a polymer's viscosity. **STK 810**

STK 811

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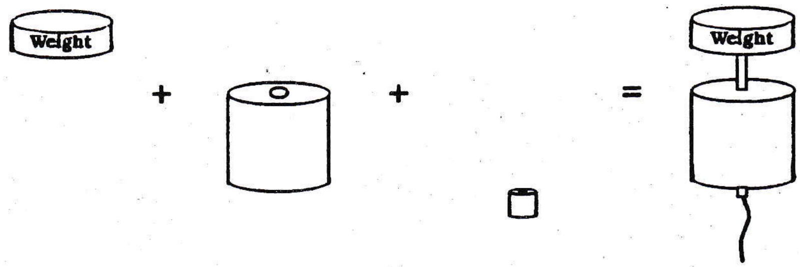
Single Condition

One Rate (One Load) | One Temp. (Barrel Temp.) | One Geometry (Orifice Size)



Single condition means that the test method uses one set of test variables.

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Melt Flow Rate (MFR) Test

- **MFR Gives an Indication of Consistency and Is Used for Quality Control**
- **MFR Is Used to Give an Indication of Viscosity Change During Processing**
- **MFR Tests for Various Plastics May Be Done Under Different Conditions**

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Participant's Notes:

Measuring Viscosity at a "Single Condition"

A "single condition" rheology test uses one temperature, one geometry, and one rate.

The most simple measure of viscosity will be at a single condition of temperature, geometry, and rate of motion. This type of measure is easily accomplished in a simple test apparatus which is commonly used in many quality control laboratories. The measure reflects only one point of the polymer's total flow behavior. However, when this single condition of measure gives a reproducible viscosity, we know the polymer is the same as what was measured earlier. In the QC lab, this type of viscosity measure is usually referred to as the melt flow rate test.

STK 811

Melt Flow Rate Test

The melt flow rate test is used to check consistency of flow at a single condition.

The melt flow rate test, also referred to as the MFR, is an easy way to check on the consistency of a polymer material. If incoming QC gets the same result on several lots of the same material, it is likely that all the material will process consistently. When the MFR is measured on virgin polymer pellets, and again on the same material after processing, a comparison of the two results gives a quick check on the quality of the processing.

MFR is generally specified at a set of conditions which are particular to each material. The temperature will be at the low end of the processing range, and the weight will be proportional to the viscosity of the material at that temperature. Because of the differences in material processing temperatures, different materials may specify different sets of conditions where the MFR test should be run.

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ASTM D1238

American Standard Test Measurement D1238 Measures Melt Flow and Reports It Under Three Different Names:

- **Melt Index (MI)**
- **Melt Flow Index (MFI)**
- **Melt Flow Rate (MFR)**

The preferred term is Melt Flow Rate (MFR).

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Participant's Notes:

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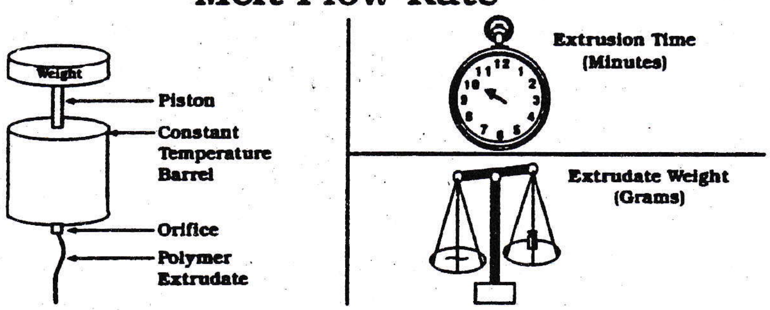
Melt Flow Rate



Melt Flow Rate = Number of Grams Per 10 Minutes

The Melt Flow Rate (MFR) is defined as the amount of material extruded in ten minutes, under a specific set of conditions (temperature, orifice, weight)

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ASTM D-1238 is the standard test for measuring melt flow rate.

ASTM D-1238

The American Standard Test Measurements (ASTM) specifies the standard conditions for measuring and reporting melt flow rate. The same standard is used when measuring Melt Index (MI), Melt Flow Index (MFI), and Melt Flow Rate (MFR). Each of these is the same test, however, the preferred name is melt flow rate. **STK 813**

The melt flow rate test defines a polymer's flow in terms of the number of grams extruded in 10 minutes at standard conditions.

Melt Flow Rate

The melt flow rate test per ASTM D-1238, specified the same three conditions we discussed earlier: geometry, temperature, and rate. The temperature is the temperature set at the barrel of the test apparatus. The geometry is that of the orifice at the bottom of the barrel through which the polymer is squeezed. And the rate of flow is determined by the weight which is placed on the melt to create the flow.

The MFR test allows the polymer melt to be extruded through the orifice during a timed period. This period may be between one and ten minutes. At the end of the specified time, the melt strand is cut off and weighed. The MFR is then calculated as the amount of polymer melt which would flow from the orifice in ten minutes at the given condition of flow. **STK 814**

STK 815

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Melt Viscosity vs. Melt Flow Rate

High Viscosity Means Low Melt Flow Rate	Low Viscosity Means High Melt Flow Rate

5 Grams / 10 Minutes Is High Viscosity	30 Grams / 10 Minutes Is Low Viscosity

The lower the viscosity - the higher the MFR.

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MV versus MFR

- Easy Flow Polymer

  High Melt Flow Rate
  Low Melt Viscosity

- Stiff Flow Polymer

  Low Melt Flow Rate
  High Melt Viscosity

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Participant's Notes:

Melt viscosity and melt flow rate are different measurements of flow for polymers.

Melt Viscosity vs. Melt Flow Rate

Melt viscosity and melt flow rate are both used to describe material flow behavior. Confusion tends to arise because the two measures of flow are quite different. A material with a high melt viscosity (resistance to flow) will give a low melt flow rate measure since very little material will extrude in a given time. Conversely, a material with low melt viscosity will show a high melt flow rate. Much of the confusion in describing a polymer's flow behavior results from improper use of the terms melt viscosity and melt flow rate, which are actually opposite descriptions of a polymer's ability to flow.

STK 815

Melt viscosity and melt flow rate are opposite measurements of rheology.

MV vs. MFR

An easy flow polymer will be described as one with a high melt flow rate but it will be a material with low melt viscosity. Conversely, a stiff flow polymer will be described by a low melt flow rate but will be a high melt viscosity material. The two descriptions of flow are quite different.

STK 816

STK 817

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Rheology

"Single Condition" Measurements

- Melt Flow Rate
- Melt Viscosity

Rheology in Processing

- Shear Rate Effects
- Temperature Effects
- Time Effects

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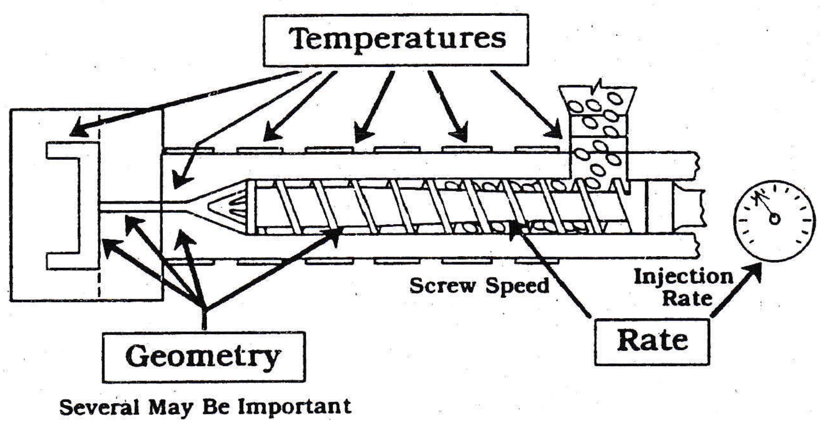

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Rheology in Processing

An understanding of the effects of shear rate, temperature, and time are necessary in order to understand rheology for processing.

So far, we have only dealt with the most simple measures of polymer flow. However, when we are interested in understanding how a polymer melt will actually work in a conversion process, we realize that the simple measures of rheology will not be sufficient. Actual process equipment uses a range of temperatures and changing geometries to heat the polymer. As the polymer melts, its rate of flow depends on the geometry it is forced to flow through. The time that the melt spends at the processing temperature also has a significant effect on the quality of the parts produced. All of these changing variables must be accounted for if we are to fully understand and make use of the polymer's flow characteristics. **STK 817**

Rheology in the Conversion Process

A real conversion process involves many conditions of temperature, geometry, and rate.

Using this graphic representation of an injection molding process, we can begin to see the variety of conditions that the melt is exposed to during its transformation from pellets to a finished part. The most obvious change that the polymer undergoes is in temperature. Heater bands and mechanical shear provide heat which changes the temperature of the polymer to get it into a flowing melt state, then the tool removes the heat to bring the polymer back into a solid state. During this process, the viscosity of the melt is continually changing.

The geometries through which the melt flows are also continually changing. Compression in the screw, flow through the nozzle, runners, gates, and the part itself all must be accounted for in the process.

Rates of flow may be related to the screw speed or the injection rate. Together, geometry and rate of flow can be described by the term shear rate. Before we describe shear rate, let us look at what is meant by shear flow. **STK 818**

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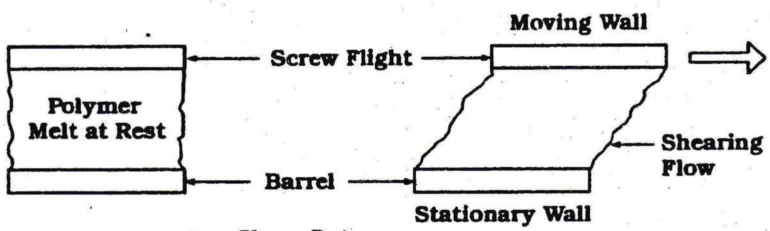
Shear Flow



Shear Rate

Shear flow is the deformation of the melt caused by the relative motion of its boundaries and the distance between the boundaries.

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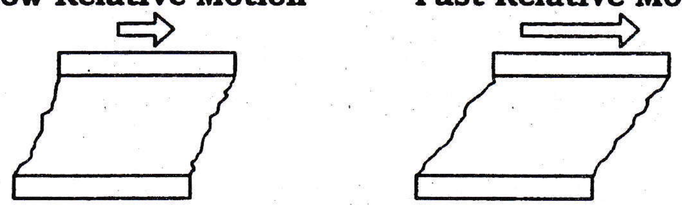
Shear Rate

Slow Relative Motion | **Fast Relative Motion**



Low Shear Rate in the Melt | **High Shear Rate in the Melt**

Shear Rate is the rate of shear movement in the polymer melt.

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Participant's Notes:____

Shear Flow

Shear flow depends on rate of motion and geometry which contains the flow.

Shear flow is simply the deformation of a melt caused by the relative motion of its boundaries and the distance between those boundaries. The faster the boundaries move relative to each other, the higher the shear velocity in the melt. Also, the smaller the separation between the boundaries, the higher the shear velocity felt by the melt. This process is most easily visualized by the motion of the melt between the screw and barrel wall in an extrusion process. The higher the screw speed (relative to the stationary wall) the higher the shear velocity in the melt. Also, the smaller the space between the root of the screw and the barrel wall, the faster the melt will be sheared at a constant screw speed. **STK 819**

Shear Rate

Shear rate describes the rate of motion of a melt within a fixed geometry.

The rate at which shear flow takes place is referred to simply as shear rate. As depicted graphically in the slide, the shear rate in the polymer is directly a result of the relative rate of motion of the boundaries which surround the melt. At a low screw speed the melt will experience a low shear rate. As screw speed increases, the shear rate on the melt will increase. **STK 820**

STK 821

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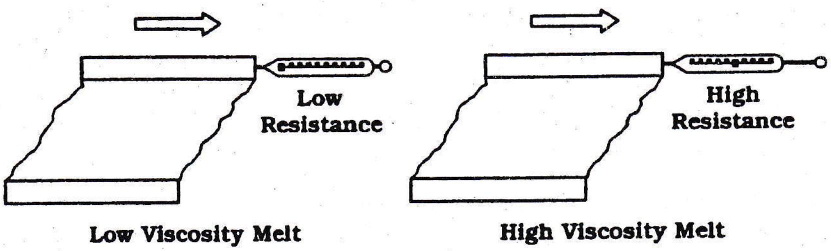
Shear Stress



At constant Shear Rate, high viscosity polymers offer more resistance to flow.

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Viscosity

- Viscosity Measures Resistance to Flow
- Viscosity Relates Shear Stress to Shear Rate
- $\text{Viscosity} = \dfrac{\text{Shear Stress}}{\text{Shear Rate}}$

8

Participant's Notes:

Shear Stress

Shear stress is a measure of the melt's resistance to flow at any given shear rate.

Now let's look at how the melt responds to shear. We know that high viscosity melts will be more resistant to flow than low viscosity melts. Shear stress is the measure of the force required to flow the polymer melt. If two melts were deformed at the same shear rate, the polymer with the higher viscosity would offer more resistance to flow and therefore exhibit a higher shear stress. Conversely, the polymer with the lower viscosity would offer less resistance to flow and exhibit a lower shear stress. In the slide, we depict this resistance by using a simple spring scale to measure the amount of force required to keep the melt moving at a constant shear rate. The high viscosity melt requires the more force to maintain a constant shear rate.

STK 821

Viscosity

Viscosity is defined as the relationship between shear stress and shear rate.

Now that we have seen there is a relationship between shear rate and shear stress, we are ready for a more formal understanding of viscosity. As shear rate changes, the shear stress in the melt may also change. This relationship between shear rate and shear stress is defined as the viscosity of the melt. Viscosity is simply a measure of a material's resistance to flow. Under conditions of constant shear rate, viscosity is directly proportional to the shear stress in the melt. Under conditions of changing shear rate (such as a conversion process), viscosity will define the shear stress (or resistance to flow) for all shear rates felt in the process. Now we begin to see how important it is to understand a material's complete viscosity when defining the use of the polymer for any conversion process.

STK 822

STK 823

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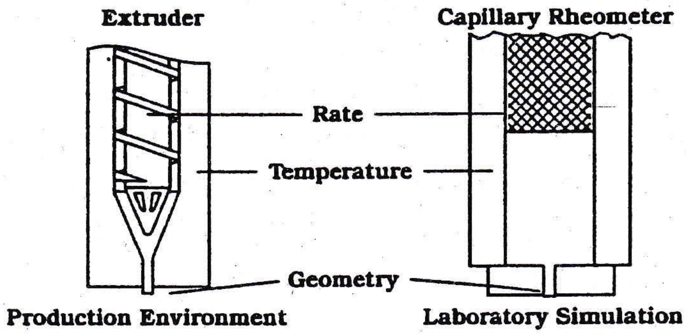
Capillary Rheometer



The Capillary Rheometer measures viscosity at conditions of rate and temperature found in the conversion process.

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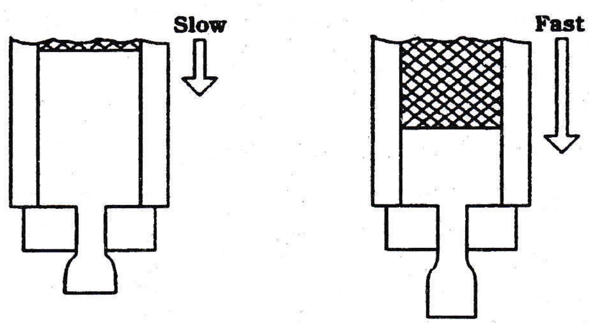
Shear Thinning in a Polymer Melt



Shear Rate affects resin viscosity.

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Participant's Notes:

Capillary Rheometer

The complex problem of how to obtain the viscosity at any shear rate is solved in the laboratory using a capillary rheometer. The capillary rheometer is a type of measuring equipment which can simulate the range of temperatures and shear rates seen in an actual conversion process. By taking measurements at controlled temperatures and varying the shear rate in an orderly fashion, the experimentalist can determine the response of the melt to all conditions of shear rate and temperature which the melt is expected to see in the process. The capillary rheometer can be thought of as a way to model the process by taking a series of single condition measurements which cover the temperatures, rates, and geometries felt in the real conversion process.

The capillary rheometer is used in the laboratory to model flow in an actual process at many conditions of temperature, and shear rate.

STK 823

Shear Thinning in a Polymer Melt

It is important to characterize the shear rate dependence of the viscosity in polymer melts because they exhibit a unique behavior. At a constant temperature, as the shear rate increases, the viscosity drops. This behavior, known as shear thinning, is a consequence of the effect of shear the on long molecules in the polymer melt. The higher the rate of shear, the less resistance the melt offers, and consequently its viscosity will be lower. This is seen when a polymer melt is squirted easily from the nozzle during an air shot but feels much thicker when a temperature probe is inserted into the melt. While this seems difficult to understand, it is quite simple when we see what is happening at the molecular level during flow .

Shear rate has a strong effect on the viscosity of polymers.

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STK 825

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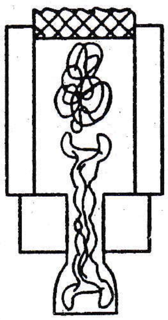
Shear Thinning

As Shear Rate increases, polymer chains align and viscosity decreases.



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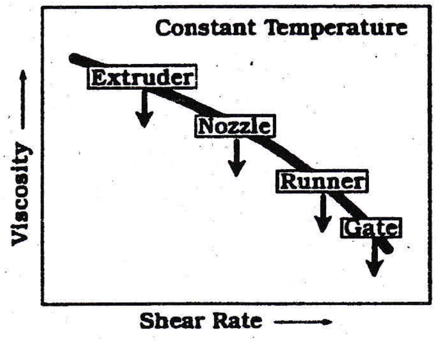
Shear Rate Effect on Viscosity



The viscosity of a polymer will typically decrease as the shear rate increases.

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Participant's Notes:

Shear Thinning

Viscosity is decreased at high shear rates due to shear thinning in the polymer.

In a stationary polymer melt, the long chain molecules will tend to find a relaxed position which is relatively random with respect to any direction. However, when we impose a shear flow on the melt, the molecules begin to flow in the direction of the shear motion. Because the molecules occupy some volume in the melt, one side of the molecule will be pulled with the flow more than the rest of the molecule. But the molecule will not break under normal shear flow conditions. Instead, it will tend to elongate in the direction of the flow. As the molecules align in the flow direction, the resistance to flow decreases because adjacent molecules can more easily slide past each other in the flow. The net effect is to lower the viscosity of the melt. The higher the shear rate, the lower the viscosity in the melt. This mechanism of flow is referred to as shear thinning.

STK 825

Shear Rate Effect on Viscosity

An actual conversion process may consist of many shear rates, each of which are described in the viscosity vs. shear rate curve.

Here is a representation of the typical response of a polymer melt to changing shear rate. As the shear rate increases, the polymer molecules align in the flow direction and the resulting viscosity of the melt is lower. This curve represents the type of shear dependence we would expect at a constant temperature in the melt. To see the relevance of this to the process, we need to understand that the shear flow throughout the process is changing. An extrusion is typically a low shear rate, while flow through the nozzle, runners, and gates of an injection process exhibit increasing shear rates on the melt. These shear rates are geometry controlled; therefore extremely small gates may lead to excessive shear rates and degradation of the melt.

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STK 827

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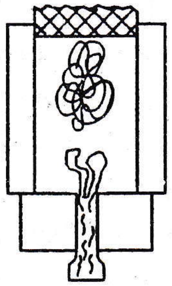
Shear Degradation

At very high shear rates polymer degradation can occur due to:



- Excessive frictional (shear) heating which causes thermal degradation.
- Breakdown of polymer chains due to excessive shear stresses.

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Participant's Notes:

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Rheology

"Single Condition" Measurements
- Melt Flow Rate
- Melt Viscosity

Rheology in Processing
- Shear Rate Effects
- Temperature Effects
- Time Effects

8

Participant's Notes:

Shear Degradation

We have shown how a shear field will stretch a polymer molecule and align it in the direction of flow. Now let's see what happens when the shear field is too high for the polymer melt.

Excessively high shear rates can cause polymer degradation during processing.

Two types of heating are known to increase the polymer's temperature: external heating supplied by the heater bands, and internal heating caused by shear work on the polymer. When the shear rate becomes excessive, such as in flowing through a very small gate, the internal shear heating of the polymer becomes a dominant factor. At very high shear rates, the local polymer temperature may increase well above the measured temperature of the melt and actually cause thermal breakdown of the polymer chains. Not only is the heat excessive, but under these very high shear conditions, the polymer chain is being stretched to its limit. Therefore, it is easy to understand how a polymer melt may be degraded by chains breaking under conditions of excessive shear. **STK 827**

Rheology

Temperature also plays an important role in determining a polymer's flow.

Having seen the effects that shear rate has on the viscosity of the melt, let's now look further into the effects that temperature has on viscosity. **STK 828**

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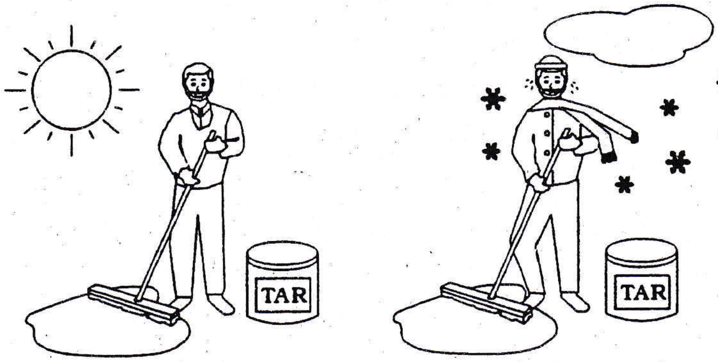
STK 829

Flow: Temperature Dependent



Temperature affects resin viscosity.

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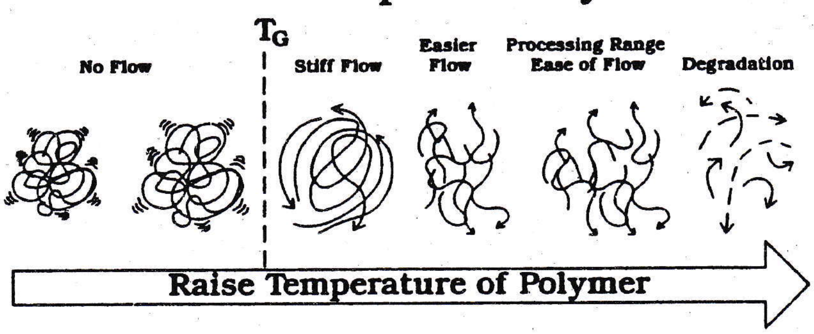
Flow in Amorphous Polymers



- Adding heat increases the space between the polymer chains.
- As more energy is applied, the space increases, and the polymer flows more easily.

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Participant's Notes:

Increasing temperature will lower the viscosity of polymers.

Temperature Dependence of Flow

The viscosity of any polymer is known to change with temperature. We know that on a cold day, polymers such as tar and oil flow very slowly and are spread with difficulty. However, when these polymers are warmed, they are found to have the ability to flow easily. These examples are exactly the same as the temperature dependence of an engineering polymer in its melt state. **STK 829**

Amorphous polymers flow above T_G but the temperature must be increased further to lower the viscosity for processing.

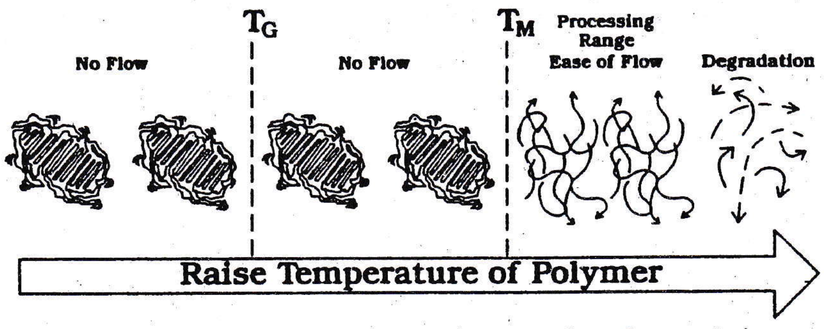
Flow in Amorphous Polymers

Before getting into measuring temperature dependence, let's review how temperature affects a polymer. In the solid state, the polymer chains are frozen into a fixed position. But as the temperature is increased, the spacing between adjacent chains increases. At Glass Transition (T_G), the chains of an amorphous polymer have sufficient separation that the mass can flow, but the viscosity is very high and the melt is not suitable for processing. Only by increasing the temperature further can the viscosity be lowered to a range suitable for processing. **STK 830**

STK 831

GE Plastics

Flowing Crystalline Polymers



- Adding heat increases the space between the polymer chains.
- The Crystalline structure prevents flow below T_M.
- The polymer will flow easily when the crystals melt.

8

Participant's Notes:

STK 832

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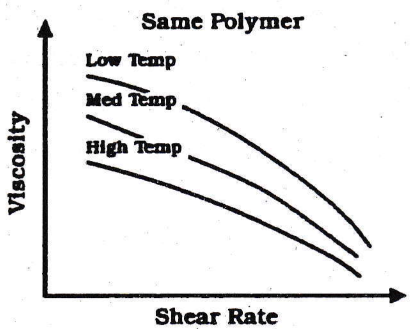
Temperature Effects



By measuring the viscosity of a polymer at several temperatures, we can determine the effect of temperature on viscosity.

8

Participant's Notes:

Flow in Crystalline Polymers

Crystalline polymers flow above T_M, at which temperature they are well above their T_G.

Similarly, in a crystalline polymer, the temperature must be increased to get the polymer to flow. However, below the crystalline melt tempearutre (T_M), the crystalline structure prevents flow. At T_M, the crystals are dissociated and the melt has a sufficiently low viscosity for processing. Notice that at T_M, the melt is now completely amorphous and well above T_G. The conditions are met for processing just like in an amorphous polymer. **STK 831**

Temperature Effects on Viscosity

Temperature effects are described using different constant temperature lines on the Viscosity vs. Shear Rate graph.

For any polymer melt, we have shown that an increasing shear rate will lower the viscosity of the melt. This relationship is described graphically by a single line on the Viscosity vs. Shear Rate graph. In the capillary rheometer, this relationship is determined for any single temperature. To show the temperature dependence of viscosity, the capillary rheometer is used again, only the polymer is held at a different temperature. If the temperature is higher, the viscosity is lower for all shear rates. Conversely, when the temperature is lower, the viscosity is higher for all shear rates. Notice that as the shear rate increases, the effect of temperature is reduced. Viscosity curves at different temperatures tend to converge at very high shear rates.

STK 832

STK 833

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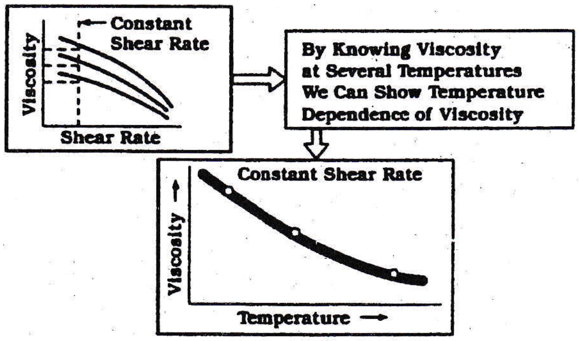
Temperature Effects



A viscosity vs. temperature curve is used to determine the processing window for the melt.

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Participant's Notes:

STK 834

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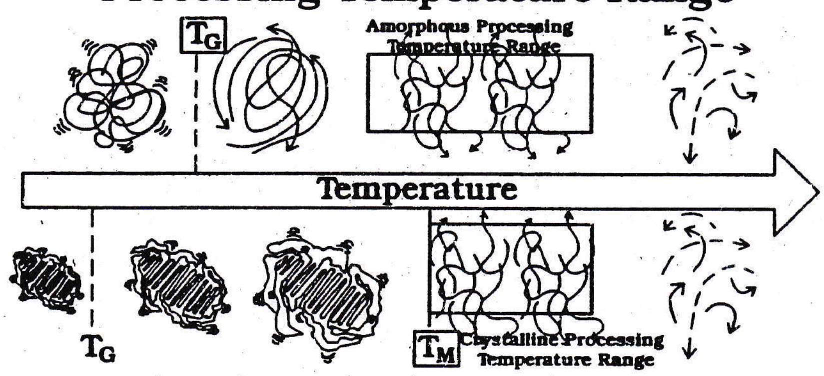
Processing Temperature Range



The processing temperature range is defined differently for amorphous and crystalline polymers.

8

Participant's Notes:

Temperature Effects

Temperature sensitivity of flow is derived by selecting values at a constant shear rate from the viscosity vs. shear rate graph.

A more useful description of the temperature dependence of viscosity can be derived from the Viscosity vs. Shear Rate graph. Here we see the presentation from the last slide in the upper left corner. These curves represent shear rate dependence of viscosity at several temperatures. Now, by choosing a constant shear rate, and reading the viscosity at several temperatures, we can construct a graph that tells us how strongly the viscosity is dependent on temperature. The graph at the bottom is the same three data points from the top graph, however, now we are looking at the temperature dependence of viscosity at a constant shear rate. The slope of this curve tells us how rapidly the viscosity will decrease as we increase the temperature. At any selected constant shear stress, the temperature dependence will be different. And for different polymers, we will see a different response to temperature. This is the curve that will be used to determine the processing window for the melt. **STK 833**

Processing Temperature Range

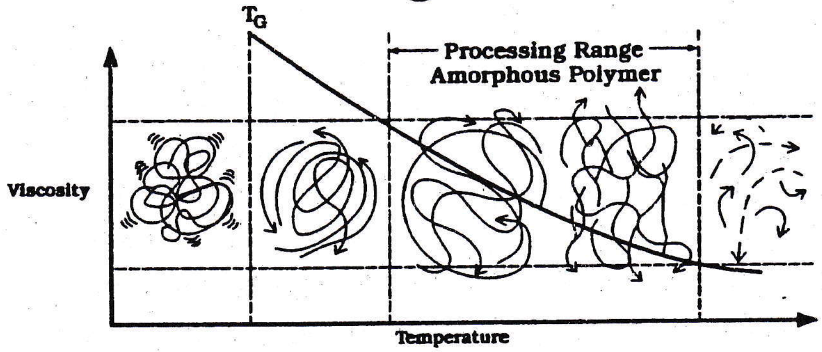
The processing range is the range of temperatures where the melt has the right viscosity for processing.

Here we have combined the representations of an amorphous and crystalline polymer to see how temperature is important in finding the processing range. We will define the processing window as the range of viscosities where the polymer is useful in processing. That is to say that the polymer is within the viscosity range where it can flow easily but not degrade. **STK 834**

STK 835

GE Plastics

Processing Window



- If the temperature is too low, the flow is too stiff.
- If the temperature is too high, the resin may degrade.

8

Participant's Notes:

STK 836

GE Plastics

Rheology

"Single Condition" Measurements

- Melt Flow Rate
- Melt Viscosity

Rheology in Processing

- Shear Rate Effects
- Temperature Effects
- Time Effects

8

Participant's Notes:

Processing Window

The processing window is determined by the viscosity range necessary for flow and may be bounded by the degradation of the resin at high temperature.

Now let's look at the temperature dependence curve we determined using the capillary rheometer and see how this is used in establishing the processing window. At low temperature, we know the melt will be more viscous. In fact, at some temperature, the viscosity will be so high that the melt will not fill the cavity. The low end of the temperature range is limited by the viscosity where the polymer will be too stiff for the process. In injection molding this is the temperature where the melt will result in a short shot. We set the minimum temperature for the process window where the viscosity is too high for the process. This temperature will be different for different polymers and may change for different processes.

The high end of the process window may be limited by the degradation of the polymer or a limitation in the process itself. As the temperature increases, the viscosity decreases. The melt flows more easily and may be found to flash the tool in injection molding or have too little melt strength for extrusion or blow molding. In any process, these limitations will establish the highest temperature of the process window. And, degradation of the melt will always put an upper limit on the temperature window. The process ranges recommended on a process data sheet will always take these factors into account. Now we can understand why the process window range may be different for different processes using the same polymer. **STK 835**

Time Effects on Viscosity

The time which the melt is held at its processing temperature is also important to quality processing.

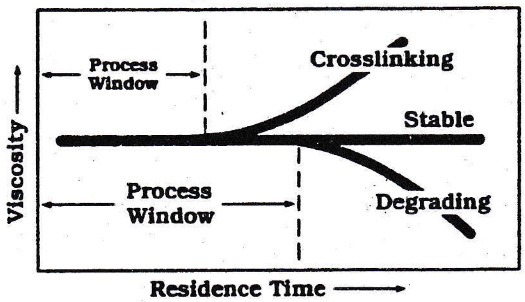
Having an appreciation for the shear effects and the temperature effects of the polymer melt is a large part of understanding how a polymer melt is affected by the process. Now let's examine Thermal Stability, the third effect which determines a polymer's utility in any conversion process. **STK 836**

STK 837

GE Plastics

Thermal Stability

Constant Temperature & Shear Rate



Thermal stability measurements define the residence time window for a given polymer.

8

Participant's Notes:

STK 838

GE Plastics

How Rheology Is Used

- Measure Polymer Consistency (Q.C.)
- Measure Degradation (Failure Analysis)
- Define Process Conditions (Setup)
- Design Tooling
- Define Process Limitations
  (Thermal Stability / Residence Time)

8

Participant's Notes:

Thermal Stability

The last effect that we will deal with is the effect of time on the polymer melt. If a polymer is very stable at a given temperature in the melt, its viscosity will be constant no matter how long we wait to make a measurement. However, polymers are sensitive to heat and will start to change when maintained for long times in their melt state.

Thermal Stability tests on a resin are used to determine the time for which the viscosity remains constant at any temperature.

Two types of changes can take place in the melt: degradation and crosslinking. Degradation will tend to lower the viscosity because the polymer chains are becoming shorter. Crosslinking will tend to increase the viscosity because the polymer is actually increasing in molecular weight. The time dependence of the process window can be determined by examining the thermal stability of the melt at its processing temperature. As long as the viscosity is constant with time, the processor can be confident that the melt will act in a consistent manner. However, going beyond the thermal stability time will cause the polymer melt to change viscosity, resulting in changes in the process. **STK 837**

How Rheology Is Used

We have examined many of the effects that flow of a polymer melt have on determining its usefulness for any conversion process. Now, let's review what we have seen.

Any measure of viscosity is dependent on three variables: geometry, rate, and temperature. At any fixed combination of these variables, we can measure a particular viscosity of the melt. In QC of the consistency of a polymer melt, a single condition of viscosity can determine if the polymer has changed versus an earlier measurement. The consistency of the polymer is determined through a single condition of viscosity measurement.

Rheology has many uses in quality control of a resin: determining part quality, defining setup conditions, designing tooling, and defining process stability.

To check the quality of a process, we need only compare the viscosity of the pellets before processing to the viscosity of the part formed in the process. If the viscosity is relatively unchanged, the process has done little to affect the quality of the polymer. This first technique is used in determining polymer degradation when the process is suspected in creating a part failure.

We have also seen that rheology is useful in determining the process window. The setup conditions for any polymer in any given process are determined using rheology.

Shear degradation results from improper sizing of restrictions such as gates in tool design. By understanding the shear rate effects of the melt, the tool designer can be sure to provide large enough flow channels to prevent degradation from shear.

And, we have seen that the rheology is a measure of the thermal stability of the melt. By knowing how long a polymer can be held at any processing temperature, the converter can determine the maximum residence time he should allow the polymer to sit at high temperatures in his process. **STK 838**

STK 839

GE Plastics

Flowing and Forming Polymers

- Understanding Flow of Plastics (Rheology)
- Thermoplastic Processing

8

Participant's Notes:

STK 840

GE Plastics

Polymer Processing

By lowering a polymer's viscosity, we can lower the force needed to make it flow, and therefore lower the amount of shear stress on the melt.

8

Participant's Notes:

Understanding rheology will allow the processor to improve part quality.

Flowing and Forming Polymers

Having a basic understanding of a polymer's flow behavior will increase the awareness that the converter will have on producing quality parts. Let's now look at the process and see where the converter can use the rheology of the polymer. **STK 839**

The processor controls the quality of his parts through controlling the viscosity of the polymer.

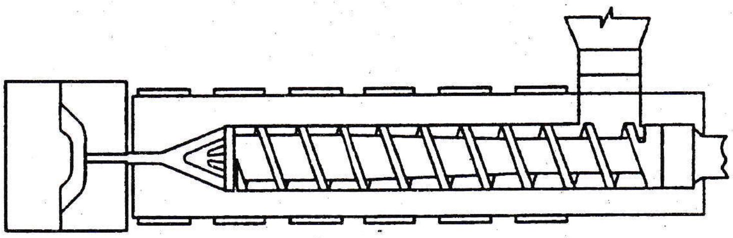
Polymer Processing

It is essential to know that the converter has control over the quality of his parts. By controlling the viscosity of the material, the converter determines the amount of shear stress that the polymer feels during the conversion process. When the shear stress in the melt is too high, the polymer may be degraded and produce inferior finished parts. The converter can lower this shear stress in the melt through increasing the temperature of the melt or providing an easier path for the polymer flow. **STK 840**

STK 841

GE Plastics

Cycle Time Effects in Injection Molding



- Control process within recommended temperature range.
- Long cycle time may require a cooler melt.

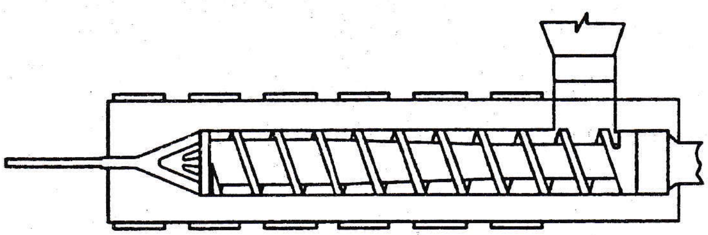
8

Participant's Notes:

STK 842

GE Plastics

Residence Time in Extrusion



- Residence time in extrusion may be shorter than injection molding.
- Allowable temperature in the barrel may be higher than injection molding.

8

Participant's Notes:

In injection molding, melt temperature, temperature profile, and cycle time must be based on thermal stability of the polymer melt.

Cycle Time Effects in Injection Molding

The cycle time in the injection process is dependent on the time required to cool the melt in the tool. However, the converter must be sensitive to what is happening in the barrel while the melt is freezing in the tool. If allowed to cook in the barrel at high temperature, the melt will degrade based on its limitations of thermal stability. When determining the cycle time, the converter must account for the thermal stability of the melt which is still residing in the barrel. The melt temperature, the temperature profile, and cycle time must be developed with an awareness of thermal stability of the melt. **STK 841**

Extrusion processes utilize different temperatures and residence times than injection molding.

Residence Time in Extrusion

An extrusion process is a continuous process and the melt is kept moving at all times. Therefore, the residence time of the melt in the extruder may be much shorter than in an injection process. When the residence time is shorter, the melt temperature may be higher without causing degradation. The thermal stability of the polymer decreases as the temperature increases; however, the short time that the polymer spends at temperature in an extrusion can allow it to be processed at a higher temperature without degradation. These effects are taken into consideration in determining the process window for an extrusion grade of a polymer. The same polymer may have a different recommended process temperature for different conversion processes.

This type of rheological characterization of a polymer melt should be determined by the material supplier in order to allow the converter to make the highest quality parts. It is the responsibility of the converter to know his process and determine how to best accommodate any resin he is using in his process. **STK 842**

STK 843

GE Plastics

Understanding Flowing and Forming

8

Participant's Notes: ______

STK 844

GE Plastics

Differentiate melt flow rate from melt viscosity.

8

Participant's Notes: ______

Summary and Performance Feedback

Understanding Flowing and Forming

During this module we examined flowing and forming of polymers and learned the important variables that hinder and improve the process. Through use of his knowledge of rheology, the processor can control the quality of his parts. **STK 843**

STK 845

GE Plastics

Melt Viscosity vs. Melt Flow Rate

- Easy Flow Polymer

  High Melt Flow Rate
  Low Melt Viscosity

- Stiff Flow Polymer

  Low Melt Flow Rate
  High Melt Viscosity

8

Participant's Notes: ____________________

STK 846

GE Plastics

Relate five different uses for rheology.

8

Participant's Notes: ____________________

STK 847

GE Plastics

How Rheology Is Used

- Measure Polymer Consistency (Q.C.)
- Measure Degradation (Failure Analysis)
- Define Process Conditions (Setup)
- Design Tooling
- Define Process Limitations
  (Thermal Stability / Residence Time)

8

Participant's Notes:

STK 848

GE Plastics

Describe how the processor can affect the quality of his parts through using his knowledge of rheology.

8

Participant's Notes:

GE Plastics

Apply Rheology to Control Part Quality

- Control the viscosity of the polymer to lower the amount of shear stress.
- Account for thermal stability when determining cycle time to reduce the likelihood of degradation.
- Accommodate for the different residence times of different conversion processes when controlling melt temperature.

8

Participant's Notes:

Module 8

Performance Feedback

1. Describe why rheology is fundamental to processing.
2. Differentiate melt flow rate from melt viscosity.
3. Describe how temperature and shear rate affect viscosity.
4. Describe how shear can cause degradation in a polymer.
5. Relate the processing window to the flow limitations of the polymer.
6. Describe two processes which limit thermal stability in a polymer.
7. Relate five different uses for rheology.
8. Describe how the processor can affect the quality of his parts through use of his knowledge of rheology.