GE Plastics

Sharing The Knowledge
Module 7

Heating, Softening, and Melting Polymers

M-PLA-0117-STK-MOD 7-12/89-00-1

STK 701

GE Plastics

Module 7

Heating, Softening, and Melting Polymers

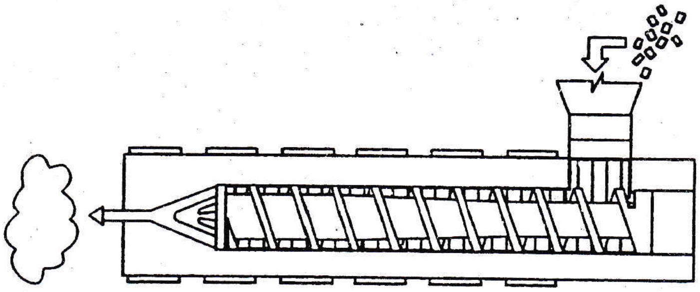
- Transition Temperatures
- Temperature Range for Processing
- Amount of Heat Necessary for Processing
- Plastic Part Production
  - Heating
  - Controlling Heat Energy

Participant's Notes:

STK 702

GE Plastics

Conversion Processes



Whatever conversion process is used, the thermoplastic pellets must be heated to raise their temperature so they soften or melt.

Participant's Notes:

Introduction

Heating, Softening, and Melting Polymers

The ability of thermoplastics to soften upon heating, form into a shape upon molding, and solidify into a part upon cooling is what makes them so unique. This module examines the phenomenon of heating, softening, and melting from both scientific and practical points of view. **STK 701**

Objectives:

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

- Describe how amorphous and crystalline polymers respond differently to heat energy. Relate these differences due to structure to: thermal transition points, temperature range for processing, and amount of heat necessary for processing.
- For a resin that you are currently working with; identify the thermal transition points, the temperature range for processing, and the amount of heat necessary for processing.
- Describe the effects of excessive heat.
- Identify four strategies to reduce mechanical heat.
- When given an actual or hypothetical situation of excessive mechanical heat, describe a realistic approach for dealing with this problem.

Conversion Processes

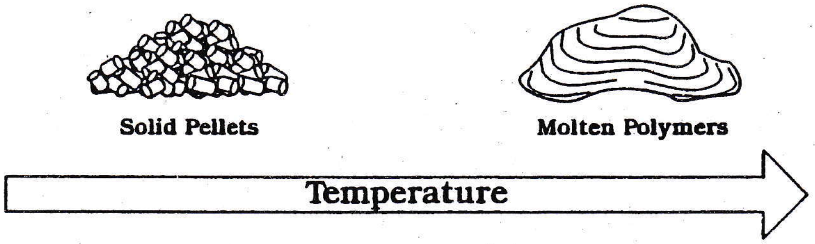
For any conversion process thermoplastics must be heated so they soften or melt.

There are many methods of converting thermoplastics into usable parts. Each conversion method requires that the thermoplastic be softened then formed. Softening or melting of a thermoplastic is accomplished by applying heat energy to raise its temperature. But how and why does the polymer soften or melt upon heating? This module attempts to unfold the mystery of polymer heating, and lend some practical advice on heating polymers during processing. **STK 702**

STK 703

GE Plastics

Heating, Softening, and Melting



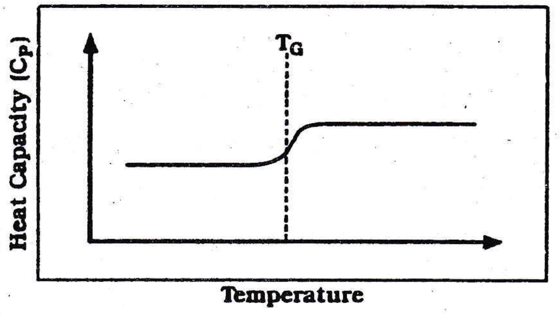
The key to successful heating is understanding how the polymer will absorb energy during processing.

Participant's Notes:

STK 704

GE Plastics

Polymer Heating Performance



A heat capacity trace can be thought of as a blueprint of how a polymer responds to heat during processing.

Participant's Notes:

It is important to know how the polymer will absorb energy during processing.

Heating, Softening, and Melting

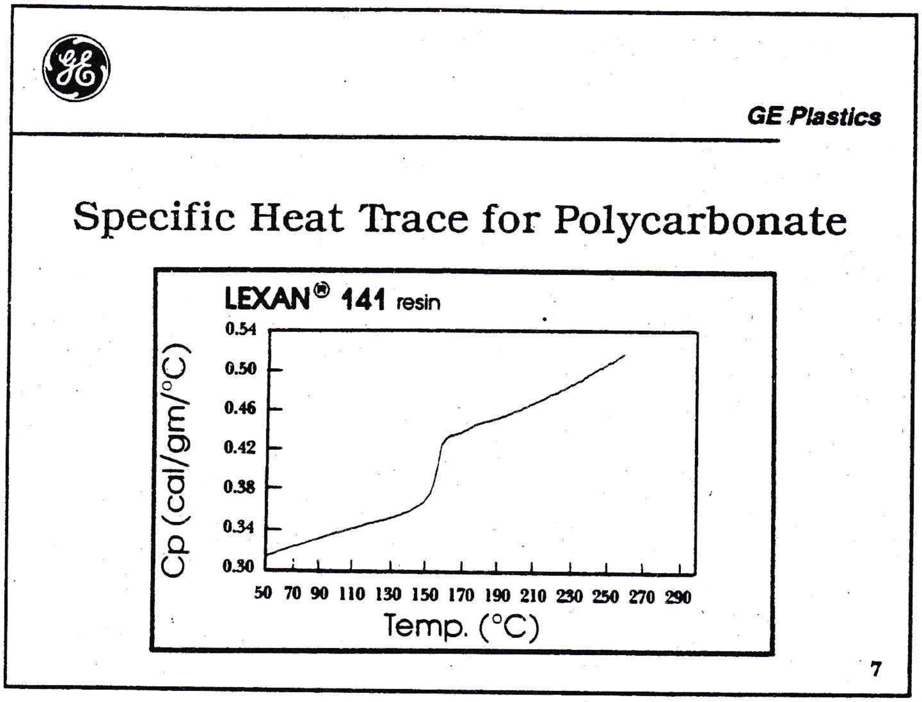
Each polymer has its own heating requirement that is outlined on the processing data sheet. It is important to understand how that information is derived for each individual material. Before you can understand that, you must understand how a polymer absorbs energy during processing. The key to successful heating is understanding how a polymer absorbs energy. **STK 703**

A heat capacity trace describes how a polymer absorbs heat.

Polymer Heating Performance

The heat capacity (CP) trace provides a blue print for polymer heating performance by indicating at what temperature a polymer will begin to soften or melt. It also provides other useful information on polymer heating and it will serve as the foundation for the many heating issues discussed in this module. **STK 704**

STK 705



GE Plastics

Specific Heat Trace for Polycarbonate

Participant's Notes:

STK 706

GE Plastics

The Heat Capacity Trace

- Points Out Temperatures Where Material Characteristics Change (Transitions)
- Indicates Appropriate Temperature Range for Processing
- Quantifies Amount of Heat Necessary for Processing

Participant's Notes:

Actual specific heat trace for polycarbonate.

Specific Heat Trace for Polycarbonate

This is an actual specific heat trace of an amorphous polymer.

STK 705

Transition Temperatures

The Heat Capacity Trace

The heat capacity trace describes what happens to a polymer as it absorbs heat energy. Upon examination, it reveals three very important pieces of information.

The heat capacity trace allows you to interpret thermal transitions where properties change.

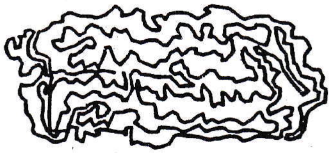
First, it points out the material's important thermal transitions. That is, it indicates at what temperatures the material characteristics change. Secondly, it indicates at what temperature the material can be processed. And thirdly, it quantifies the amount of heat required to process the material. We'll discuss each of these items individually.

STK 706

Polymer Structure

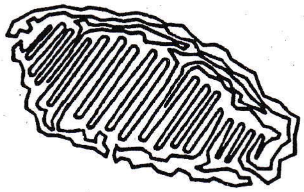
Amorphous Model

A Random Entanglement of Polymer Chains



Crystalline Model

Areas in which Molecular Chains Lie Side by Side in an Ordered Fashion



Because amorphous and crystalline polymers have very different structures, they also have very different heating requirements.

Participant's Notes:

Amorphous Polymers

- Are Structural Below the Glass Transition Temperature (T_G) and Rubbery Above It
- Rely on Physical Entanglements of the Molecular Chains for Structural Properties Below T_G

Participant's Notes:

Amorphous and crystalline polymers have different structures.

Because of the different structure, they also exhibit different heat absorption.

Polymer Structure

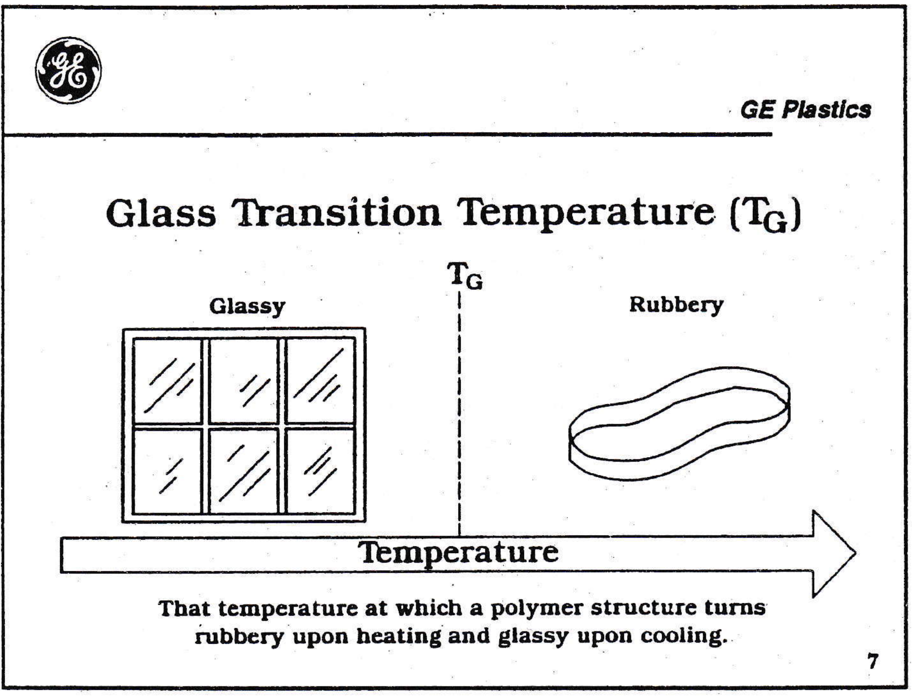
Polymers are comprised of many long chain-like molecules of repeating structural units. The way these molecular chains align themselves determines the structure of the polymer and ultimately has a great impact on the material's heat absorption characteristics. Because amorphous and crystalline polymers have very different structures, they also have very different heating requirements.

To be "amorphous" means literally, to be without structure. Amorphous polymers are characterized by the randomness of their entangled polymer chains. This top drawing is a simple model depicting amorphous structure. **STK 707**

Amorphous polymers are "glassy" below the glass transition temperature and "rubbery" above it.

Amorphous Polymers

Due to its molecular structure, an amorphous polymer is structural; that is, solid below its glass transition temperature and rubbery above it. Below its glass transition temperature, the amorphous polymer depends on the random physical entanglement of its polymer chains for its structural properties. **STK 708**



GE Plastics

Glass Transition Temperature (T_G)

T_G

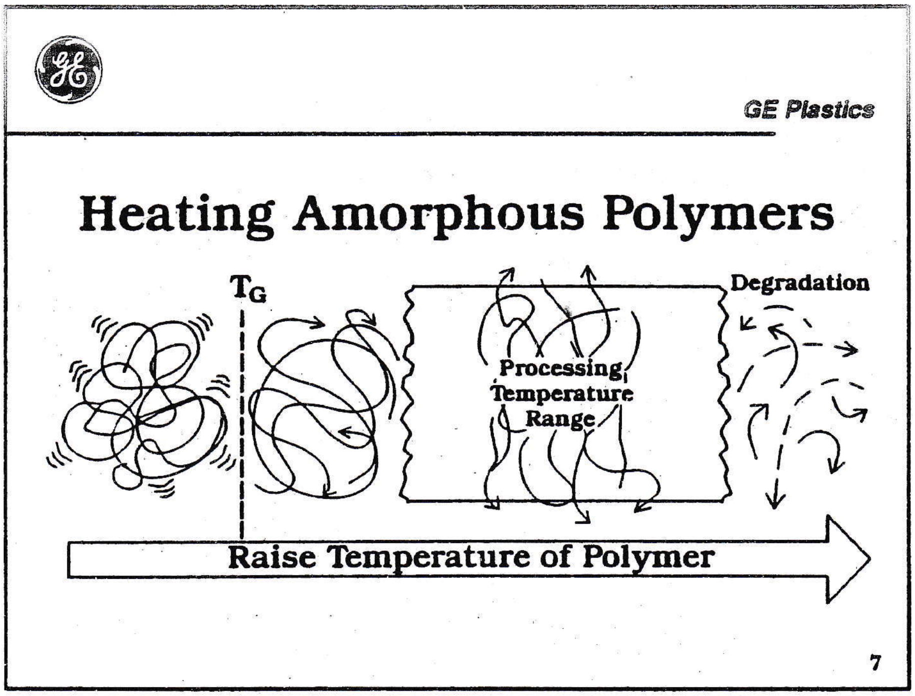
Glassy

Rubbery

Temperature

That temperature at which a polymer structure turns rubbery upon heating and glassy upon cooling.

Participant's Notes:



GE Plastics

Heating Amorphous Polymers

T_G

Processing Temperature Range

Degradation

Raise Temperature of Polymer

Participant's Notes:

At glass transition temperature polymers become "rubbery" upon heating and "glassy" upon cooling.

Glass Transition Temperature

Every polymer has a glass transition temperature (T_G). It is the temperature at which a material turns rubbery upon heating and glassy upon cooling. Below T_G, an amorphous polymer is hard, like glass, and structurally sound. Above T_G, an amorphous material begins to soften, becoming rubbery and increasingly pliable. The terms "glassy" and "rubbery" are actually referring to glass and rubber. Glass has very high glass transition temperature - over 1000°F - so it is most often below its T_G and therefore glassy and rigid. Rubber, on the other hand, has a very low glass transition temperature - below 0°F - so it is most often above its T_G and therefore rubbery and soft.

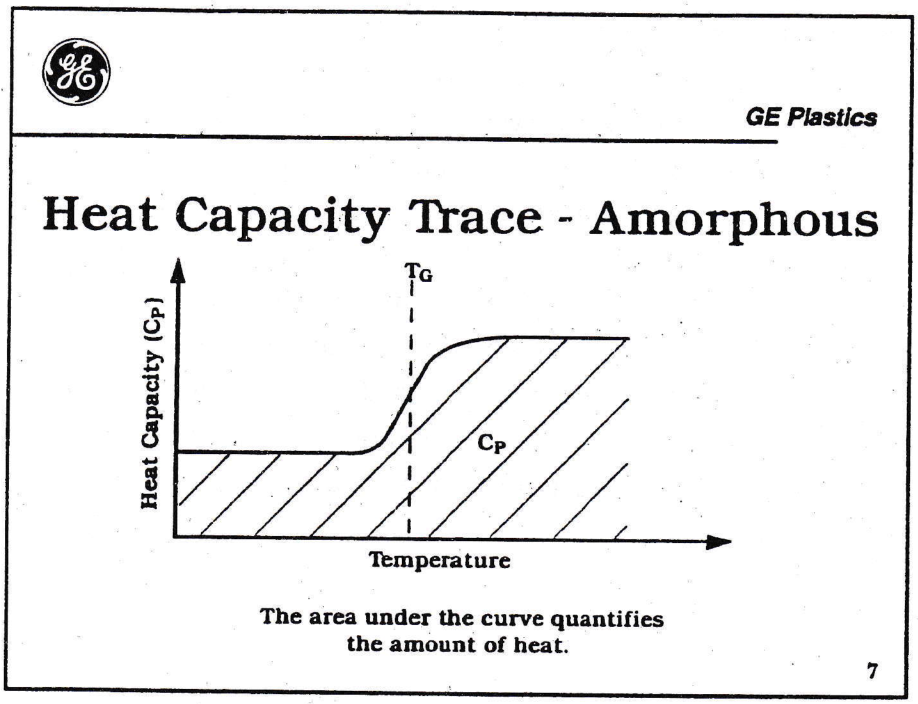
STK 709

As heat is added to amorphous polymers the space between molecular chains is increased and the polymers begin to flow. Above T_G the polymer molecules are able to begin to flow.

Heating Amorphous Polymers

As stated, an amorphous polymer is comprised of random entanglements of molecular chains. Below T_G, these chains twist, tangle, and collapse in on themselves and their neighbors forming a tight structural "knot." Adding heat energy increases the space between the molecular chains causing them to loosen. As more heat is added the chains slowly begin to slide back and forth and eventually flow. T_G is the temperature at which the chains loosen enough to begin to flow.

STK 710



STK 711

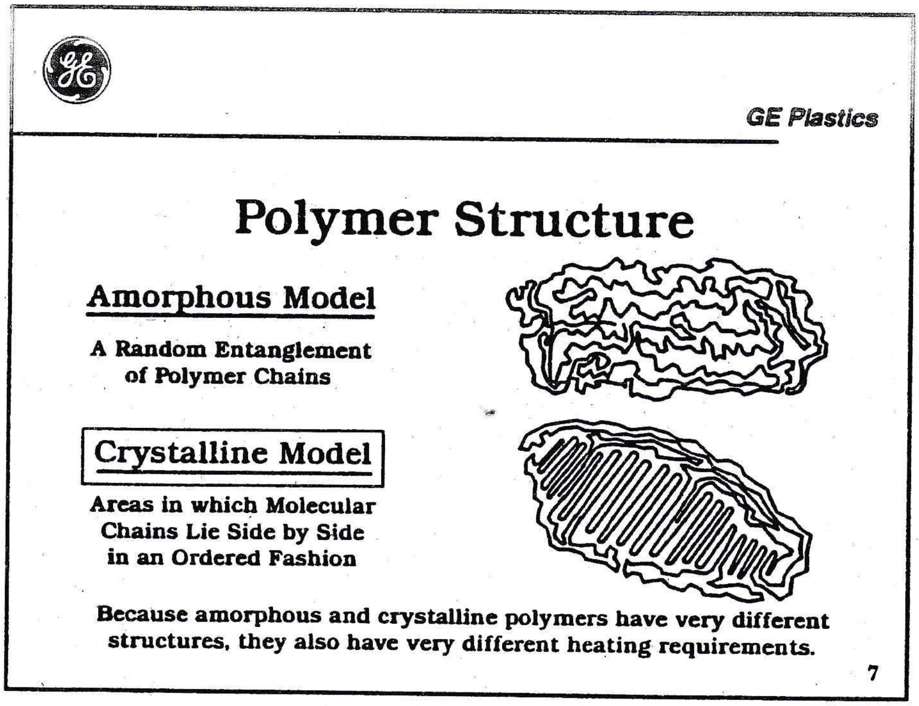
GE Plastics

Heat Capacity Trace - Amorphous

The area under the curve quantifies the amount of heat.

7

Participant's Notes:____



STK 712

GE Plastics

Polymer Structure

Amorphous Model

A Random Entanglement of Polymer Chains

Crystalline Model

Areas in which Molecular Chains Lie Side by Side in an Ordered Fashion

Because amorphous and crystalline polymers have very different structures, they also have very different heating requirements.

7

Participant's Notes:____

Heat Capacity Trace - Amorphous

The heat capacity trace of an amorphous resin describes the amount of heat necessary to increase the temperature of the resin above its T_G and into the processing temperature range.

The shape of the heat capacity curve is similar for all amorphous polymers; however the actual coordinates change with each individual resin and resin grade. The trace quantifies how much heat energy is necessary to increase the temperature of the polymer above its T_G and allow it to flow. Notice that the curve is constant, then rises dramatically, then levels off again. This dramatic rise indicates the additional heat energy absorbed by the polymer going through its glass transition. The material's T_G range is defined by the width of that rising slope, where there is sufficient heat energy available for the material to begin to flow.

STK 711

Polymer Structure

The difference in the way amorphous and crystalline polymers absorb heat is due to the presence of crystals in the crystalline material.

Crystalline polymers absorb energy differently than amorphous polymers due to their structural differences. Whereas amorphous polymers are comprised of a random mass of molecular chains, crystalline polymers contain areas of order in which their chains lie side-by-side in a regular fashion. These regions of order where the chains line up and lie closely together are referred to as crystals. The presence of these crystals is referred to as crystallinity. This bottom drawing is a simple model depicting crystalline structure.

STK 712

STK 713

GE Plastics

Crystalline Polymers

- Have Low Energy "Crystal" Regions
- These "Crystals" Are Present Below the Melting Point (T_M) but Are Dissociated by Heating Above It

Participant's Notes:

STK 714

GE Plastics

Melting Point (T_M)

Temperature at which Crystalline Regions Dissociate (Break Apart) and Are Able to Flow

Participant's Notes:

Polymer crystals are broken apart (dissociated) when heated above the melting point (T_M).

Crystalline Polymers

Due to its molecular structure, a crystalline polymer contains low energy regions of crystallinity. Below a crystalline polymer's melting point, there is not enough energy available to force these low energy crystalline regions to break apart and flow. At the polymer's melting point, these crystals dissociate. **STK 713**

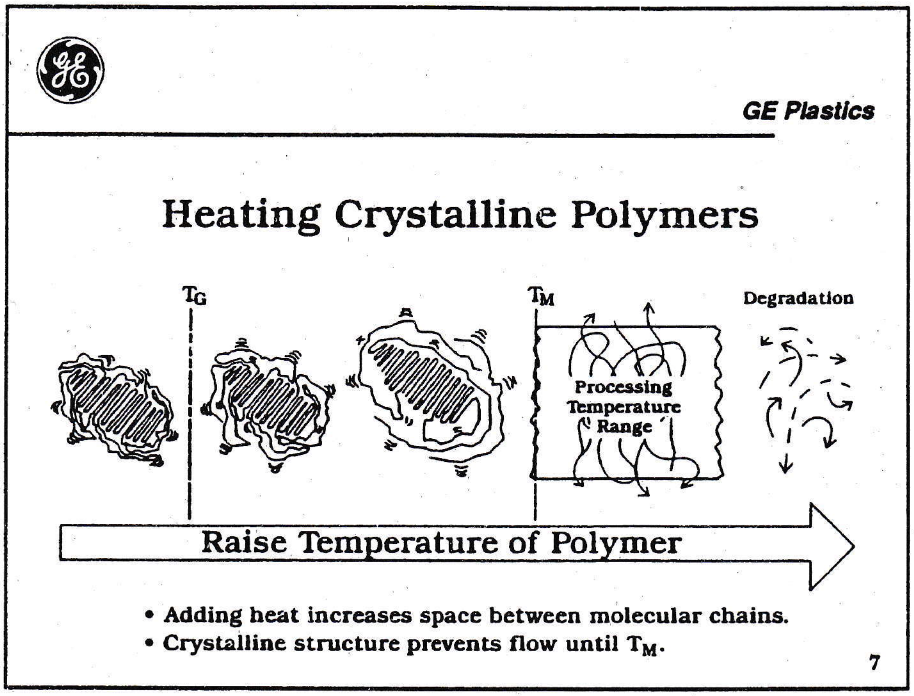
Melting point (T_M) is the temperature at which crystalline regions dissociate and are able to flow.

Melting Point

Every crystalline polymer has a melting point. It is the temperature at which the crystalline regions break apart and begin to flow.

STK 714

STK 715

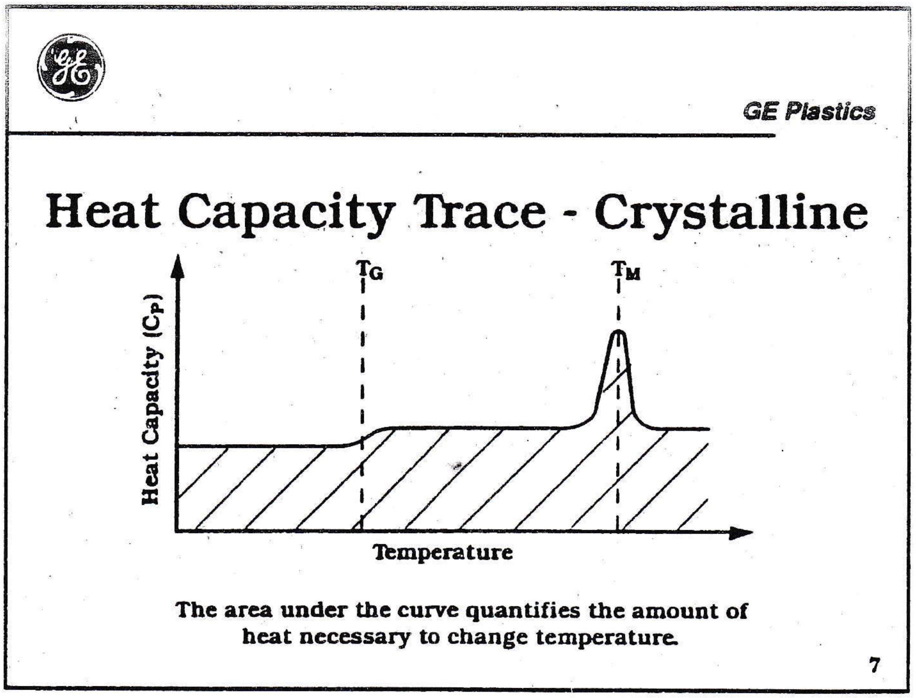


Heating Crystalline Polymers

- Adding heat increases space between molecular chains.
- Crystalline structure prevents flow until T_M.

Participant's Notes: ____________________

STK 716



Heat Capacity Trace - Crystalline

The area under the curve quantifies the amount of heat necessary to change temperature.

Participant's Notes: ____________________

Heating Crystalline Polymers

As heat is added to crystalline polymers the space between molecular chains is increased but the crystalline structure prevents flow until T_M.

As heat energy is applied to a crystalline material, its molecular chains begin to vibrate. Above T_G, they continue to vibrate but do not separate or flow. Above T_M, enough energy is finally present to break apart the tightly packed molecular chains in the crystalline regions. When these crystals finally dissociate, the molecular chains immediately begin sliding past each other easily due to the high level of energy already stored in the structure. Therefore, a crystalline material is said to melt and flow above its T_M. The crystalline polymer's processing temperature range begins at T_M. **STK 715**

Heat Capacity Trace - Crystalline

The heat capacity trace of a crystalline polymer quantifies the amount of heat necessary to change the temperature.

The heat capacity trace of a crystalline polymer is similar to that of an amorphous polymer with the added feature of a melting spike associated with the melting of the crystal structure. The shape of the heat capacity curve is similar for all crystalline polymers; however the actual coordinates change with each individual resin and resin grade. The trace quantifies how much heat energy is necessary to increase the temperature of the polymer above its T_M and allow it to flow. The material's T_M falls at the peak of the curve where there is enough heat energy present for the material to flow. At this point the structure has stored so much energy that the molecules begin sliding past one another easily and flowing enough for processing. **STK 716**

STK 717

GE Plastics

The Heat Capacity Trace

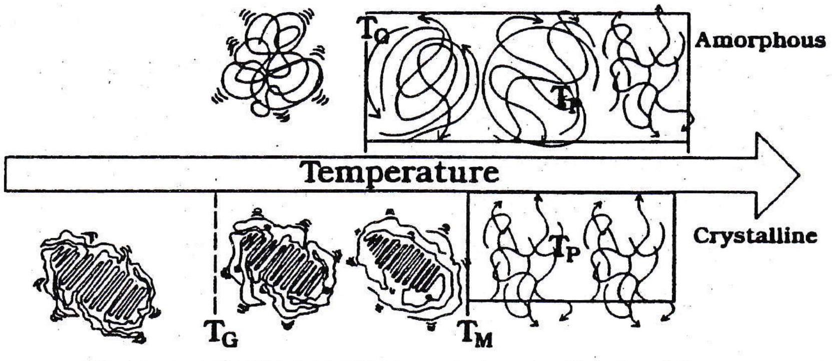
- Points Out Temperatures Where Material Characteristics Change (Transitions)
- Indicates Appropriate Temperature Range for Processing
- Quantifies Amount of Heat Necessary for Processing

Participant's Notes:

STK 718

GE Plastics

Polymer Processing Temperature Range



The processing temperature range is an estimate of the temperature needed to allow a material to flow.

Participant's Notes:

As heat is added to crystalline polymers the space between molecular chains is increased but the crystalline structure prevents flow until T_M.

Heating Crystalline Polymers

As heat energy is applied to a crystalline material, its molecular chains begin to vibrate. Above T_G, they continue to vibrate but do not separate or flow. Above T_M, enough energy is finally present to break apart the tightly packed molecular chains in the crystalline regions. When these crystals finally dissociate, the molecular chains immediately begin sliding past each other easily due to the high level of energy already stored in the structure. Therefore, a crystalline material is said to melt and flow above its T_M. The crystalline polymer's processing temperature range begins at T_M. **STK 715**

The heat capacity trace of a crystalline polymer quantifies the amount of heat necessary to change the temperature.

Heat Capacity Trace - Crystalline

The heat capacity trace of a crystalline polymer is similar to that of an amorphous polymer with the added feature of a melting spike associated with the melting of the crystal structure. The shape of the heat capacity curve is similar for all crystalline polymers; however the actual coordinates change with each individual resin and resin grade. The trace quantifies how much heat energy is necessary to increase the temperature of the polymer above its T_M and allow it to flow. The material's T_M falls at the peak of the curve where there is enough heat energy present for the material to flow. At this point the structure has stored so much energy that the molecules begin sliding past one another easily and flowing enough for processing. **STK 716**

STK 717

GE Plastics

The Heat Capacity Trace

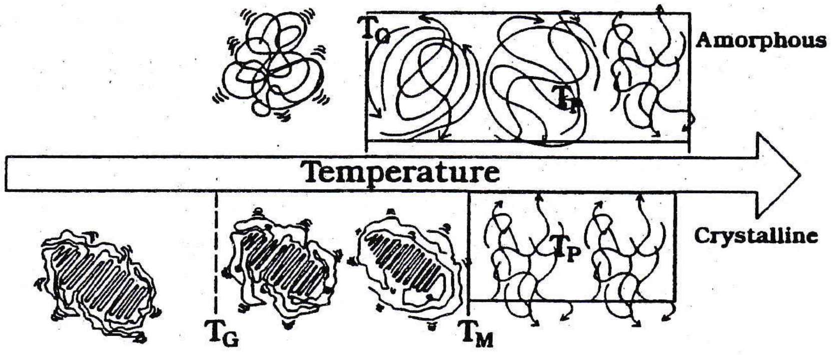
- Points Out Temperatures Where Material Characteristics Change (Transitions)
- Indicates Appropriate Temperature Range for Processing
- Quantifies Amount of Heat Necessary for Processing

Participant's Notes:

STK 718

GE Plastics

Polymer Processing Temperature Range



The processing temperature range is an estimate of the temperature needed to allow a material to flow.

Participant's Notes:

Temperature Range

The heat capacity trace indicates the appropriate temperature range for processing.

The Heat Capacity Trace

The heat capacity trace points out the temperature at which the amorphous material softens and the temperature at which the crystalline polymer melts. It indicates the appropriate temperature range for processing the resin, and provides a blueprint for processing.

STK 717

The polymer processing temperature range is an estimate of the temperature needed in order for a material to flow.

Polymer Processing Temperature

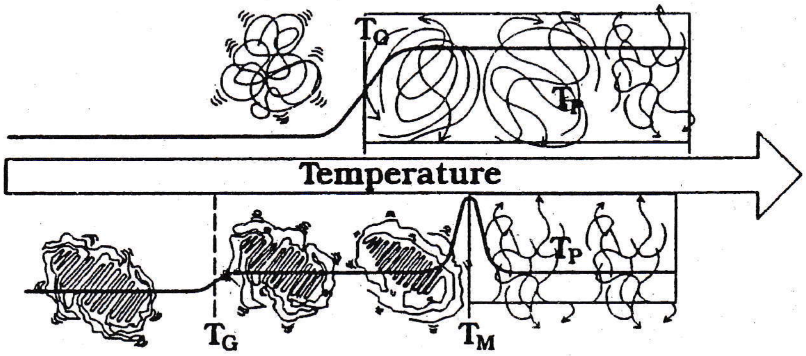
The polymer processing temperature range is an estimate of the temperature needed in order for a material to flow. This temperature must be above T_G for an amorphous polymer and above T_M for a crystalline polymer.

STK 718

STK 719

GE Plastics

Polymer Processing Temperature Range



Participant's Notes:

STK 720

GE Plastics

Polymer Degradation

- Adding Too Much Heat Will Cause a Loss in Polymer Properties (Degradation)
- Heating Too Long Will Cause Degradation (Extended Residence Time)

Participant's Notes:

Processing Temperature Range

The processing temperature range can be estimated from the heat capacity trace.

The beginning of an amorphous polymer's processing temperature range is an estimated temperature derived from its own heat capacity trace. The high end is another estimated temperature, below which the material will flow freely but above which the material may begin to degrade.

The beginning of a crystalline polymer's processing range is T_M and is derived from its heat capacity trace. The crystalline polymer will not flow until T_M. **STK 719**

Polymer Degradation

Excess heat causes excess degradation.

Adding heat to a polymer melt will increase the flow, but adding too much heat will cause excessive degradation resulting in a loss of polymer properties. Heating a polymer too long will cause degradation and may result in substandard parts. **STK 720**

STK 721

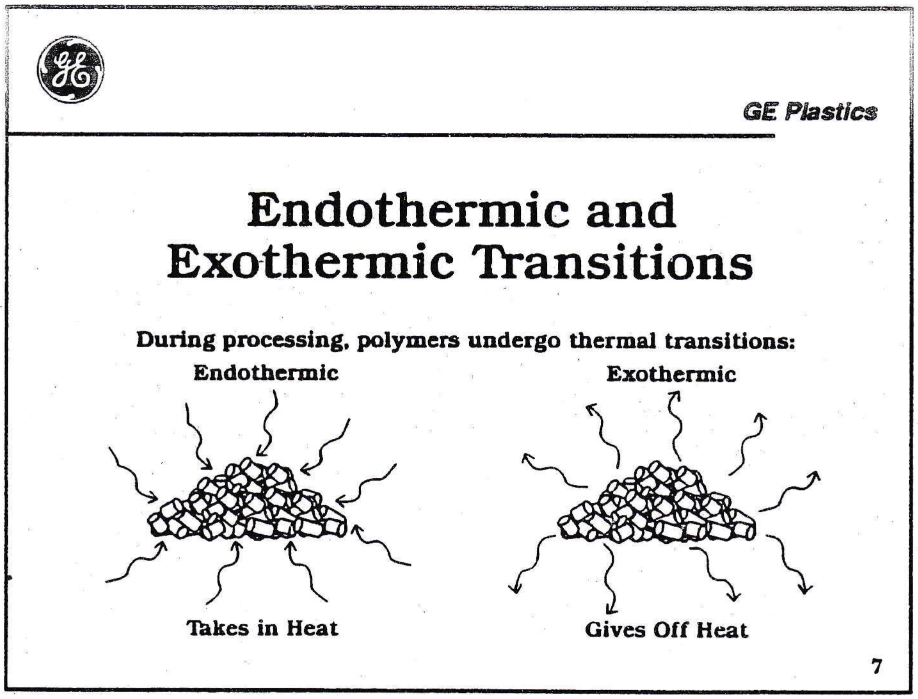
GE Plastics

The Heat Capacity Trace

- Points Out Temperatures Where Material Characteristics Change (Transitions)
- Indicates Appropriate Temperature Range for Processing
- Quantifies Amount of Heat Necessary for Processing

Participant's Notes:____

STK 722



GE Plastics

Endothermic and Exothermic Transitions

During processing, polymers undergo thermal transitions:

Participant's Notes:____

Amount of Heat

The heat capacity trace quantifies the amount of heat necessary for processing.

The Heat Capacity Trace

The heat capacity trace points out the important thermal transitions thus indicating the material's processing range. It also quantifies the amount of heat necessary for processing. **STK 721**

There are two basic types of thermal transitions.

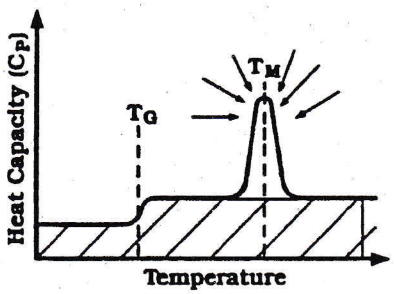
Endothermic and Exothermic Transitions

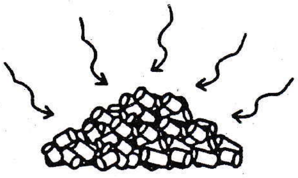
During processing, a polymer goes through two types of thermal transitions: endothermic and exothermic. Upon heating, the polymer takes in heat energy. This is called an endothermic transition. Upon cooling, the polymer gives off heat energy. This is called an exothermic transition. This module is concerned with the endothermic transition. Exothermic transitions are discussed in Module 9, Cooling and Freezing Polymers. **STK 722**

STK 723

GE Plastics

Endothermic Transition





The peak on the Crystalline Heat Capacity Trace indicates the amount of additional energy needed to melt the crystals.

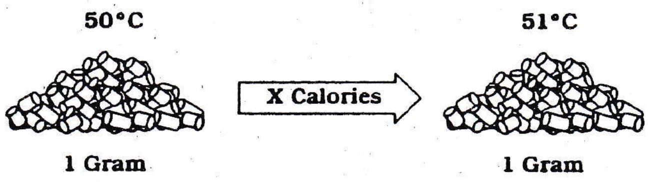
Participant's Notes:

STK 724

GE Plastics

Specific Heat Capacity (C_P)

Specific Heat Capacity is the energy required to heat one gram of material one degree centigrade.



50°C

X Calories

51°C

1 Gram

1 Gram

1 Cal / Gram / °C = 1 BTU / Lb. / °F

Participant's Notes:

Endothermic Transition

The melting peak on the crystalline heat capacity trace is an endothermic transition.

During the endothermic transition, the polymer is actually absorbing heat energy. The peak on the crystalline heat capacity trace indicates the amount of additional energy the polymer must absorb to melt its crystals. **STK 723**

Specific Heat Capacity (Cp)

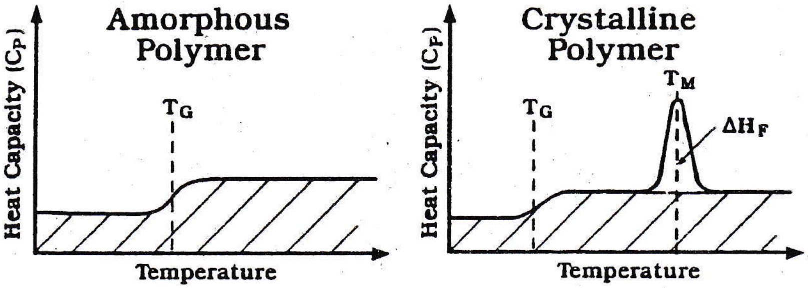
Heat capacity trace is defined as the quantity of heat required to change the temperature of one gram of material one degree centigrade.

The heat capacity trace can quantify this heat energy, providing the converter with practical processing information. Specific Heat Capacity (Cp) is the energy, in calories, required to heat one gram of material one degree centigrade. It is expressed in calories per gram per degree centigrade (cal/gram/°C). The heat capacity trace defines the amount of energy required to raise a material's temperature. **STK 724**

STK 725

GE Plastics

Heat Capacity Trace
Amorphous and Crystalline Polymers



- A crystalline polymer requires additional heat energy to melt its crystals
- This additional energy is the Heat of Fusion (ΔH_f)

Participant's Notes:

STK 726

GE Plastics

Heat of Fusion (Melting)

Heat of Fusion (ΔH_f) is the amount of heat needed to melt a crystalline structure (calories per gram or BTU's per pound).

Participant's Notes:

Heat Capacity Trace
Amorphous and Crystalline Polymers

A crystalline polymer requires additional heat energy to melt its tightly packed crystals.

Energy to heat is determined by calculating the area under the heat capacity trace. As you can see, the crystalline polymer requires additional heat energy to melt its crystalline regions. This additional energy is called the Heat of Fusion (ΔH_f). **STK 725**

Heat of Fusion (Melting)

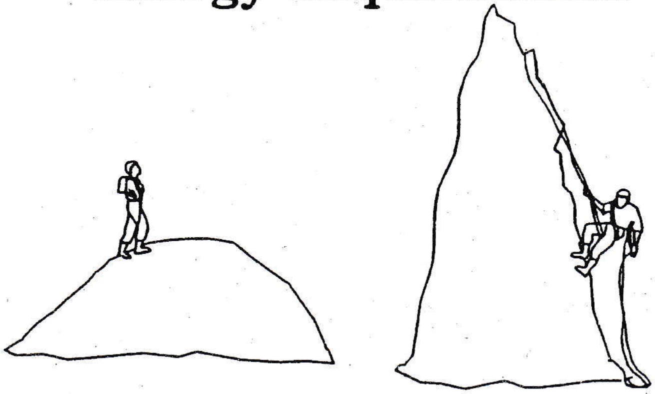
Heat of fusion is the amount of heat needed to melt a crystalline structure.

Heat of Fusion (ΔH_f) is the amount of heat needed to melt a crystalline polymer's crystalline regions. It is determined by calculating the area under the peak in the heat capacity trace and expressed in calories per gram or BTUs per pound. **STK 726**

STK 727

GE Plastics

Energy Requirements



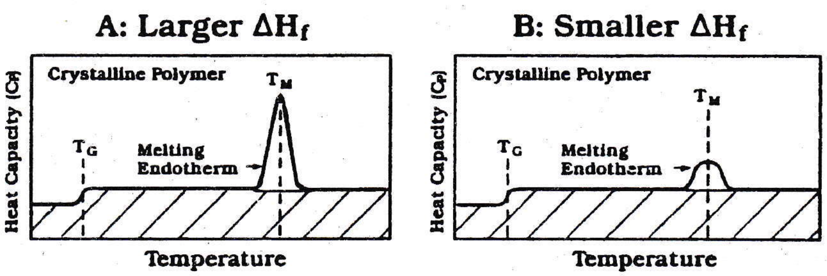
The larger the melting peak, the more energy required for melting.

Participant's Notes:

STK 728

GE Plastics

Melting Peaks



It takes more energy to melt A than B, since the heat of fusion (ΔH_f) for A is greater than for B.

Participant's Notes:

The larger the melting peak, the more energy required for melting.

Energy Requirements

A large peak in a material's heat capacity trace will contain more area underneath it than a smaller peak. Therefore, the larger the melting peak, the more energy required to melt that polymer's crystals. It can be likened to the great amount of energy it takes to scale a large mountain peak as opposed to the relatively small amount of energy it takes to traverse a small hill. **STK 727**

It takes more energy to melt crystalline A than B because it has larger melting peak.

Melting Peaks

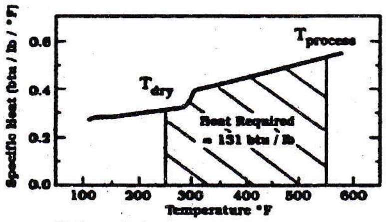
From this example then, you can see it will take more energy to melt endotherm A than endotherm B. Crystalline polymer A has a higher ΔH_f than crystalline polymer B. **STK 728**

STK 729

GE Plastics

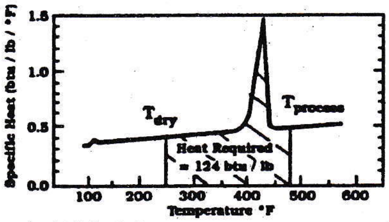
Calculating the Heat Requirement

Typical Amorphous Polymer



Polycarbonate

Typical Crystalline Polymer



Polybutylene
Terephthalate
PBT

The area under the trace gives us the heat required to increase the temperature of a polymer from drying temperature to its processing temperature.

Participant's Notes:

STK 730

GE Plastics

Heat Capacity Trace

(On Heating) Defines:

T_G	Glass Transition Temperature
T_M	Melting Point
C_P	Heat Capacity (Also Called Specific Heat)
ΔH_f	Heat of Fusion (Melting)

By understanding how to read the heat capacity trace, we can determine the proper heating specifications for processing.

Participant's Notes:

Calculating the Heat Requirement

The area under the heat capacity trace gives us the heat requirement for each polymer.

We know that the vertical axis represents the specific heat capacity in either cals/gram/°C or BTUs/lb/°F. And we know that the horizontal axis represents the temperature of the polymer. Finally, we know that the area under the trace represents the amount of heat energy being absorbed by the polymer. Then by calculating the area under the trace from the material's drying temperature to its processing temperature, we can determine the total amount of heat energy required for processing. By understanding that the amount of energy required for processing is quantifiable, the converter can monitor the heating process to be certain that additional energy is not being spent and therefore wasted. Ultimately, it could result in substantial operational cost savings. **STK 729**

Heat Capacity Trace

The heat capacity trace gives us valuable information to help determine the proper heating specifications for processing.

The heat capacity trace reveals an amorphous material's glass transition temperature (T_G) and a crystalline material's melting temperature (T_M) which lets us determine each material's processing range. It also reveals each material's heat capacity or specific heat, and a crystalline material's heat of fusion (ΔH_f) which lets us determine each material's heating requirement.

Understanding the science of heating helps us determine the proper heating specifications for processing a polymer material. Now having laid this foundation, let's look at the actual process of heating, softening, and melting during injection molding. **STK 730**

STK 731

GE Plastics

Plastic Part Production

Material Dictates Processing

Processing Dictates Performance

Participant's Notes:

STK 732

GE Plastics

Four Steps in Polymer Processing

- Drying
- Heating, Softening and Melting Plastic
- Flowing and Forming the Melt
- Cooling and Freezing Plastic

The dried thermoplastic pellets are heated to soften
or melt them and then are formed into a part and cooled.

Participant's Notes:

Plastic Part Production

The material and the processing dictate performance.

Plastic Part Production

The material's heat capacity trace will indicate the processing parameters. Adherence to these parameters will ultimately affect part performance. If, for example, a material is heated beyond its processing range, it will degrade, resulting in substandard parts.

STK 731

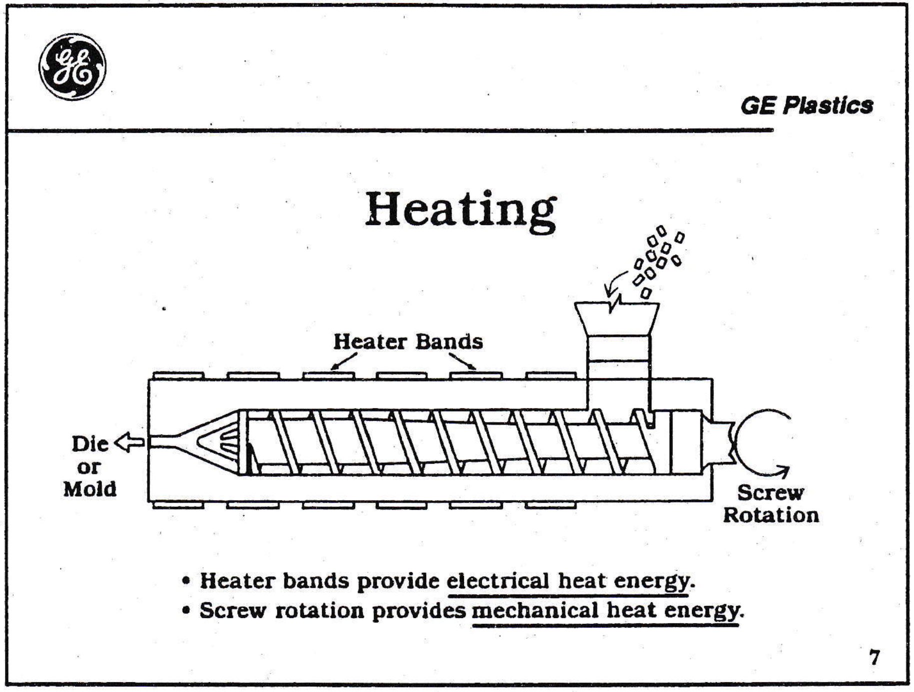
Heating, softening, and melting is one of four steps in polymer processing.

Four Steps in Polymer Processing

Polymer processing can be broken down into four steps: drying, heating, flowing, and cooling. Drying is discussed in depth in Module 6, and flowing & forming and cooling & freezing is discussed in Modules 8 and 9 respectively. This module is a close examination of the second step: heating, softening, and melting.

STK 732

STK 733



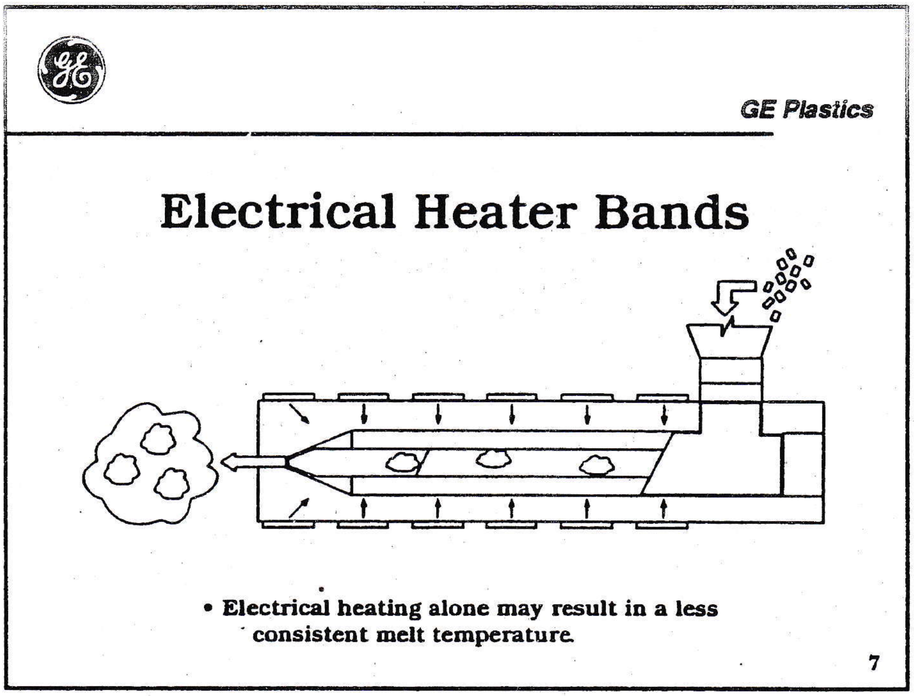
GE Plastics

Heating

- Heater bands provide electrical heat energy.
- Screw rotation provides mechanical heat energy.

Participant's Notes:

STK 734



GE Plastics

Electrical Heater Bands

- Electrical heating alone may result in a less consistent melt temperature.

Participant's Notes:

A combination of electrical energy and mechanical energy raises the temperature of the polymer to its processing range.

Heating

A combination of electrical and mechanical energy heat the thermoplastic pellets during processing. Heater bands on the exterior of the barrel provide the electrical heat energy, while the rotation of the screw within the barrel provides the mechanical heat energy.

STK 733

Electrical heating alone may result in a less consistent melt temperature.

Electrical Heater Bands

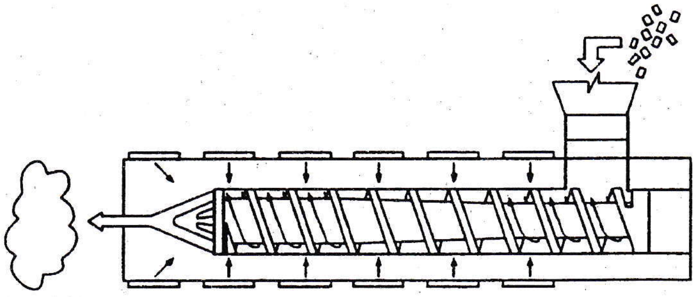
The heater bands are placed on the outside of the barrel but they direct heat energy through to the interior to heat the material. But plastics are excellent insulators and therefore do not transfer heat readily. Consequently, the electrical heating bands would probably only heat the material along the surface of the barrel if it weren't for the mixing action of the screw.

STK 734

STK 735

GE Plastics

Screw Rotation



A rotating screw exposes the plastic to the heated barrel, mixing and conveying it forward, providing a more consistent melt temperature.

Participant's Notes:

STK 736

GE Plastics

Controlling Polymer Heating

- Electrical Heat Energy
- Mechanical Heat Energy

Participant's Notes:

Screw rotation exposes the plastic to the heated barrel while mixing and moving it forward for a more consistent melt temperature.

Screw Rotation

The rotating screw exposes all the material to the heated barrel as it mixes and conveys it forward. Using the rotating screw provides a more consistent melt temperature than electrical heating alone.

STK 735

Controlling Heat Energy

Electrical

Electrical heat energy.

Controlling Polymer Heating

It is the challenge of the converter to control this combination of electrical and mechanical heat energy in order to achieve the proper material processing temperature throughout the run. Since the electrical heat energy is adjustable and quantifiable, it is the easier of the two to control.

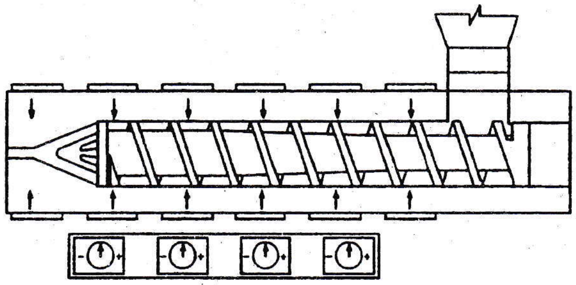
STK 736

STK 737

GE Plastics

Electrical Heat Energy

Barrel temperatures are set according to information derived from the heat capacity trace.



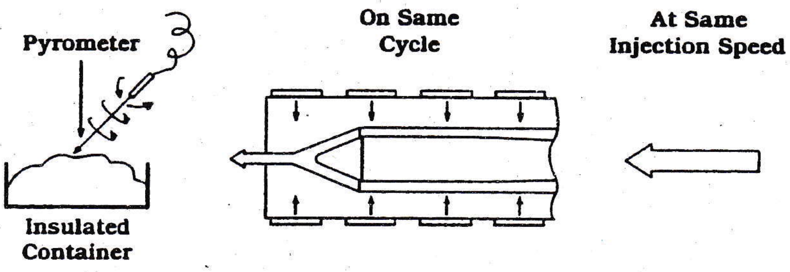
The settings may not accurately represent the the temperature of the melt.

Participant's Notes:

STK 738

GE Plastics

Melt Air Shot



A melt air shot will reveal the actual temperature of the melt if taken on cycle.

Participant's Notes:

The heat capacity trace can guide us in setting initial barrel temperature.

Settings on the barrel may not accurately represent the temperature of the melt.

Electrical Heat Energy

The barrel temperatures are set according to information found on the processing data sheet and derived from the heat capacity trace. It is assumed that the material enters the barrel at its drying temperature and should leave the barrel at its ideal processing temperature. The heater bands are typically set to increase the temperature of the melt incrementally until injection. But the settings on the heater bands may not accurately represent the temperature of the melt.

STK 737

A melt air shot will reveal the actual temperature of the melt.

The air shot must be done under representative molding conditions.

Melt Air Shot

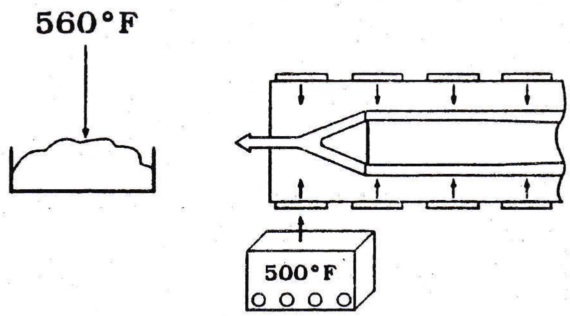
The actual temperature of the melt can be obtained by taking a melt air shot into an insulated container, then measuring its temperature using a needle-type thermocouple of a portable pyrometer. The melt air shot should only be taken after the machine and running conditions have been stabilized, and under the exact same cycle conditions as the actual shot.

STK 738

STK 739

GE Plastics

Actual Melt Temperature



The temperature of the melt may actually be hotter than indicated by the heater band controller due to mechanical heating.

Participant's Notes:

STK 740

GE Plastics

Mechanical Heat Energy

- Mixing action of the screw causes frictional (shear) heating.
- Screw design causes compressive heating (adiabatic).

Participant's Notes:

Mechanical heating may raise the temperature of the melt above the temperature indicated by the electrical settings.

Actual Melt Temperature

The melt air shot reveals the actual temperature of the melt upon injection. And it may reveal that the material is running much hotter than the heater band controllers indicate. This difference in material temperature is caused by the additional mechanical heat energy being applied to the melt. **STK 739**

Mechanical heat energy is the result of frictional (shear) heating caused by the mixing action of the screw and adiabatic heating.

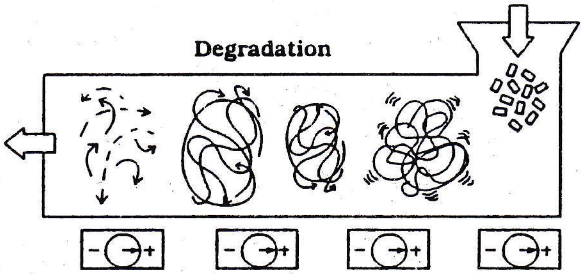
Mechanical Heat Energy

There are two types of mechanical heating going on inside the barrel. The first is the frictional (shear) heating being caused by the mixing action of the rotating screw. The second is called adiabatic or compressive heating which is caused by the design of the screw. The screw in the injection molding machine is tapered so that the space inside the barrel decreases as the thermoplastic is plasticized. The material is compressed as it is conveyed forward for injection causing additional mechanical heating. **STK 740**

STK 741

GE Plastics

Excessive Mechanical Heat



Excessive mechanical heat may increase the temperature of the melt beyond the recommended processing range causing molded part defects.

Participant's Notes:

STK 742

GE Plastics

Controlling Polymer Heating

- Electrical Heat Energy
- Mechanical Heat Energy

Participant's Notes:

Excessive mechanical heat may cause degradation due to temperature increase above recommended ranges.

Excessive Mechanical Heat

Although the heater bands may have been set to the proper processing temperature, excessive mechanical heating may increase the temperature of the melt beyond the recommended processing range and cause the material to degrade. Excessive degradation in the material results in low performance parts and probable defects.

STK 741

Controlling Heat Energy

Mechanical

Mechanical heat energy.

Controlling Polymer Heating

It is important to learn to control the mechanical heat energy being applied to the material.

STK 742

STK 743

GE Plastics

Reducing Mechanical Heating

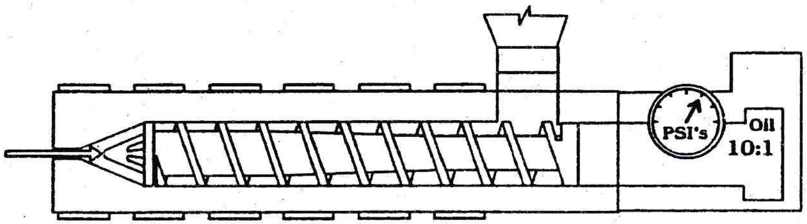
- Reduce Back Pressure
- Slow Screw Speed
- Reverse Temperature Profile
- Alter Screw Design

Participant's Notes:

STK 744

GE Plastics

Back Pressure



Material Pressure
(500 to 1000 psi)

Oil Back Pressure
(50 to 100 psi)

As the material accumulates in front of the screw, it exerts pressure on the backward moving screw.

Participant's Notes:

Reducing Mechanical Heating

Reduce back pressure.

If a melt air shot indicates that the material is running too hot, the processor can try to reduce the mechanical heat in a number of ways. Reducing the back pressure may be the first strategy taken. The specific order will vary according to the processing conditions.

STK 743

Back Pressure

As material accumulates in the front of the screw it exerts pressure on the backward moving screw.

As we've seen, the reciprocating screw first acts to mix the material and convey it forward for injection. As more and more material is conveyed forward, it begins to accumulate in the front of the screw exerting pressure on the screw and pushing it backward. Back pressure is the resistance placed on the back of the screw. Back pressure is applied to slow the screw return so it can finish plasticizing the melt. What the processor may not realize is that although the meter indicates back pressure of 50 to 100 psi, that translates to 500 to 1000 psi of material pressure.

STK 744

STK 745

GE Plastics

Minimum Back Pressure

Since back pressure increases mechanical heating, it should be set at the minimum level for good melt consistency.

Participant's Notes:

STK 746

GE Plastics

Reducing Mechanical Heating

- Reduce Back Pressure
- Slow Screw Speed
- Reverse Temperature Profile
- Alter Screw Design

Participant's Notes:

Minimum Back Pressure

Increased back pressure increases mechanical heating.

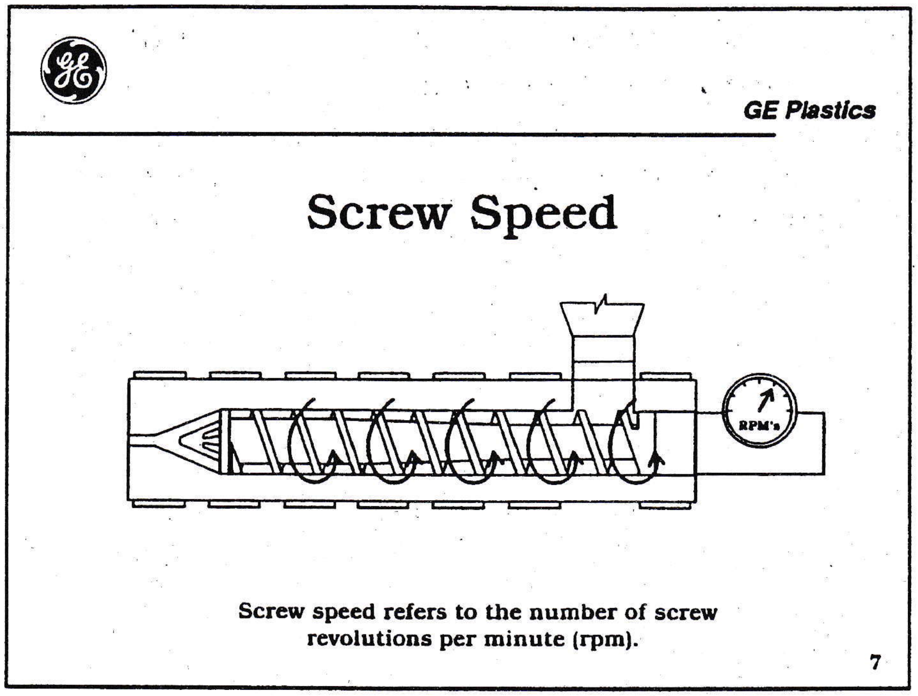
Since back pressure increases mechanical heating, it should be set at the minimum level for good melt consistency. Reducing the back pressure on the material may help to reduce the mechanical heating.
STK 745

Reducing Mechanical Heating

Slow screw speed.

If reducing the back pressure doesn't help, the converter could try slowing the screw speed.
STK 746

STK 747



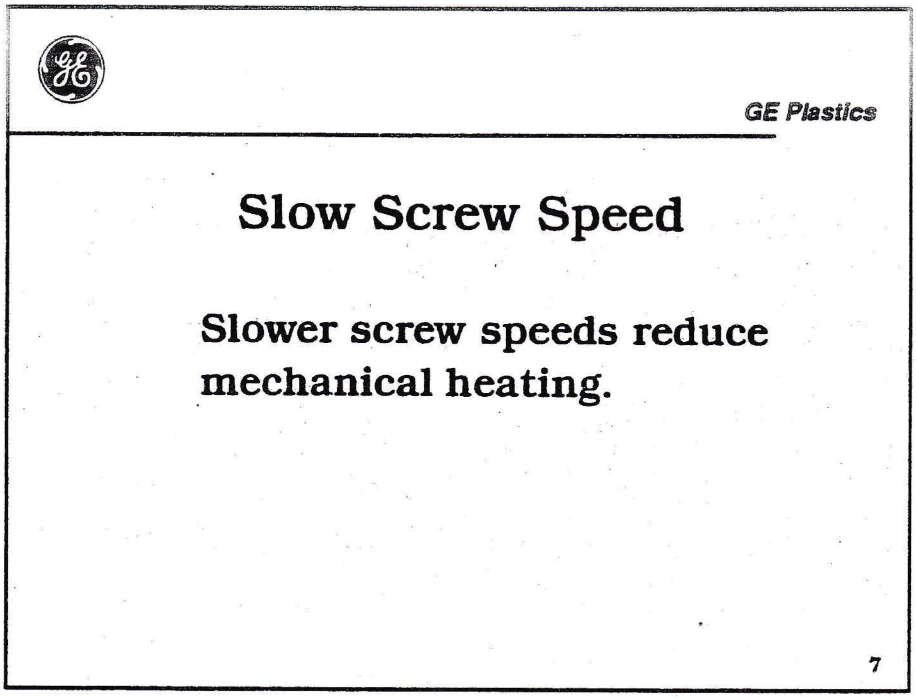
GE Plastics

Screw Speed

Screw speed refers to the number of screw revolutions per minute (rpm).

Participant's Notes:

STK 748



GE Plastics

Slow Screw Speed

Slower screw speeds reduce mechanical heating.

Participant's Notes:

Screw speed is the number of rotations per minute (rpm).

Screw Speed

The screw speed refers to the number of revolutions the screw makes per minute (rpms). The faster the screw turns, the greater the mechanical heating. **STK 747**

Reducing screw speed can reduce mechanical heating.

Slow Screw Speed

Since faster screw speeds increase mechanical heating and the screw has to return on the switch before the clamp opens, the screw should be given as much time as possible to rotate back into position after injection. Slowing the screw speed as it rotates back may help to reduce the amount of mechanical heating. **STK 748**

STK 749

GE Plastics

Reducing Mechanical Heating

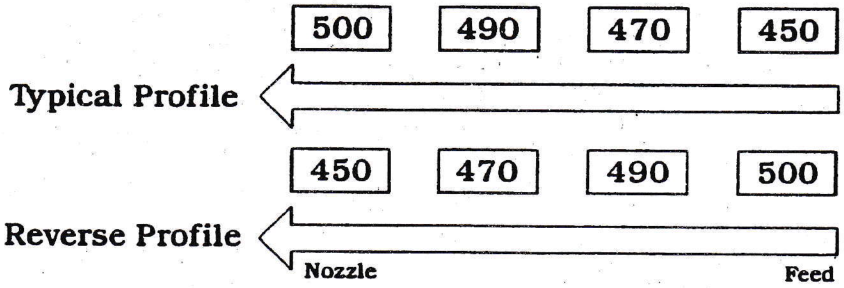
- Reduce Back Pressure
- Slow Screw Speed
- Reverse Temperature Profile
- Alter Screw Design

Participant's Notes:

STK 750

GE Plastics

Reverse Temperature Profile



Reversing the temperature profile lowers the viscosity of the polymer sooner and therefore reduces the amount of mechanical heat generated.

Participant's Notes:

One way to reduce mechanical heating is by reversing the temperature profile on the barrel.

Reducing Mechanical Heating

If a melt air shot indicates that the material is running too hot, there are various steps the converter can take to try to reduce the mechanical heating. One approach is to reverse the temperature profile.

STK 749

Reversing the temperature profile lowers the viscosity of the polymer sooner and results in less mechanical heating.

Reverse Temperature Profile

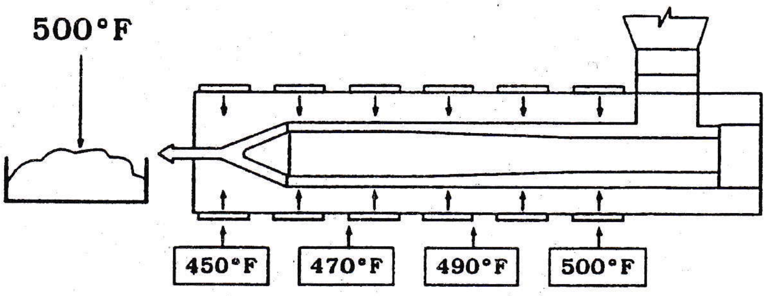
In the typical processing profile, the heater bands are set at temperatures rising incrementally from the back of the barrel to the front. The temperature at the front of the barrel is the ideal processing temperature for the material. But as we've seen, the temperatures on the barrel indicate the temperature of the electrical heater bands, not the temperature of the melt. The temperature of the melt may actually be much higher than the barrel dials indicate.

Reversing the temperature profile, that is, setting the temperature to decrease incrementally from the back of the barrel to the nozzle, reduces the viscosity of the melt sooner. A lower viscosity melt has less resistance and therefore creates less mechanical heating.

STK 750

STK 751

Stabilizing the Melt



Reversing the temperature profile may stabilize the temperature of the melt.

Participant's Notes:

STK 752

Reducing Mechanical Heating

- Reduce Back Pressure
- Slow Screw Speed
- Reverse Temperature Profile
- Alter Screw Design

Participant's Notes:

Stabilizing the Melt

Reversing the temperature profile may stabilize the temperature of the melt.

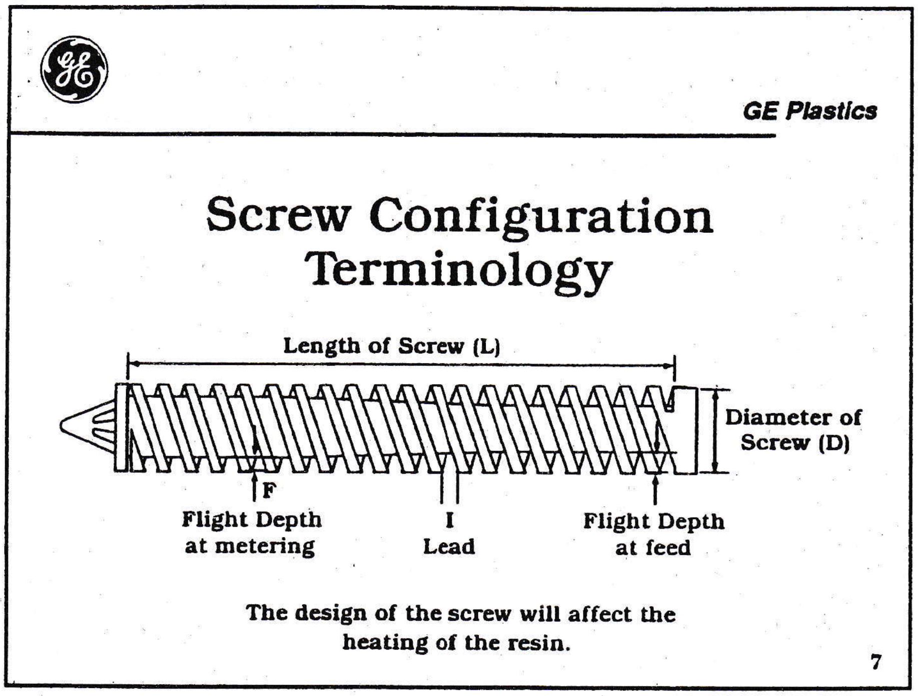
Consequently, reversing the temperature profile may actually stabilize the temperature of the melt, providing the perfect combination of electrical and mechanical heat energy. **STK 751**

Reducing Mechanical Heating

Alter screw design.

If all other methods for reducing mechanical heating have been attempted and failed, the converter may have to alter the screw design. **STK 752**

STK 753



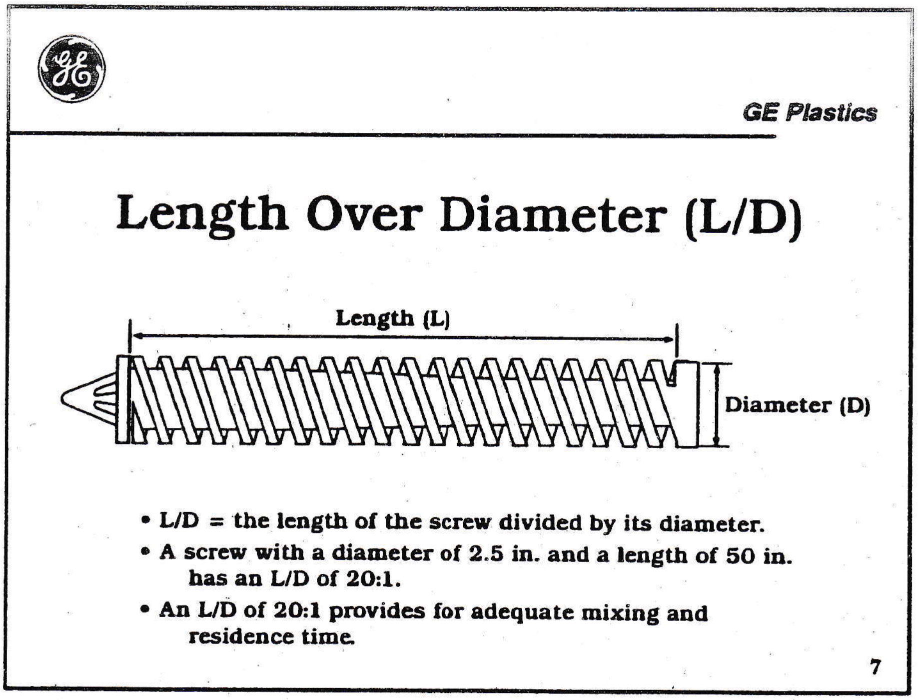
GE Plastics

Screw Configuration Terminology

The design of the screw will affect the heating of the resin.

Participant's Notes:______________________________

STK 754



GE Plastics

Length Over Diameter (L/D)

- L/D = the length of the screw divided by its diameter.
- A screw with a diameter of 2.5 in. and a length of 50 in. has an L/D of 20:1.
- An L/D of 20:1 provides for adequate mixing and residence time.

Participant's Notes:______________________________

Screw Configuration Terminology

Screw configuration terminology is important to understand.

The screw is crucial to the injection process and the design of the screw greatly affects the mechanical heating of the resin. In order to understand how the design of the screw impacts mechanical heating, it is important first to understand screw configuration terminology.

The reciprocating screw has a tapered core that is narrower at the feed section, where the plastic enters the barrel, and wider at the metering section, where the plastic is accumulated for injection. This kind of tapering is typical of an injection molding screw. The specific dimensions of a screw can greatly affect the processing of a material. A screw has several critical dimensions: length (L); diameter (D); flight depth (F); and lead (I).

L is the length of the screw, from the first flight to the last. **D** is the diameter of the flights of the screw. The screw's tapered core has nothing to do with its diameter. **F** is the flight depth, or the distance from the edge of a flight to the core of the screw. The flight depth is therefore greater at the narrower feed section than at the wider metering section of the screw. **I** is the lead, or the distance between the flights of the screw. Screw designs vary by these dimensions. The important design ratios to understand are L/D (Length over Diameter) and the compression ratio. **STK 753**

Length over Diameter (L/D)

An L/D of 20:1 is suggested.

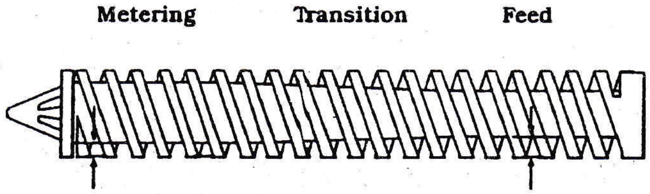
L/D describes the relationship between the length of the screw and its diameter, and is an important indication of material residence time. It describes the length of the screw versus its diameter. The higher the L/D, the longer the screw is in relation to its diameter. A high L/D means less mechanical energy if the screw is designed correctly. A short L/D means less residence time, but may cause excessive mechanical heating. An L/D of 20:1 is suggested to ensure enough residence time for thorough mixing without adding excessive mechanical energy.

STK 754

STK 755

GE Plastics

Compression Ratio



- Compression ratio = the flight depth at the feed section divided by the flight depth at the metering section.
- A reduction in channel depth from .4 in. to .2 in. yields a compression ratio of 2:1.
- A compression ratio of 2:1 is suggested to provide adequate compression.

Participant's Notes:

STK 756

GE Plastics

Understanding Heating, Softening, and Melting Polymers

Participant's Notes:

Compression Ratio

The compression ratio describes the relationship between the feed depth and the meter depth of the screw. It indicates to what degree the core of the screw is tapered by describing the flight depth at the feed section versus the flight depth at the metering section The compression ratio is an important indication of the degree to which the plastic will be compressed as it is conveyed from the feed to the metering section of the screw.

A 2:1 reduction in flight depth from the feed to the metering section will provide adequate compression without excessive heating.

The compression ratio describes the volumetric transition of the screw. If, for example, the compression ratio were 2:1, then the volume of the material in the metering section is reduced by one half from the feed section. A high compression ratio such as 3:1 or 4:1, may create excessive mechanical energy which could cause the material to degrade. Therefore a compression ratio of 2:1 is suggested to provide adequate compression. **STK 755**

Summary and Performance Feedback

Understanding Heating, Softening, and Melting Polymers

It is important for the converter to understand the science behind the processing. By understanding how a polymer material responds to heat energy, the converter can better anticipate its behavior and make practical compensations and choices in his processing design. **STK 756**

STK 757

GE Plastics

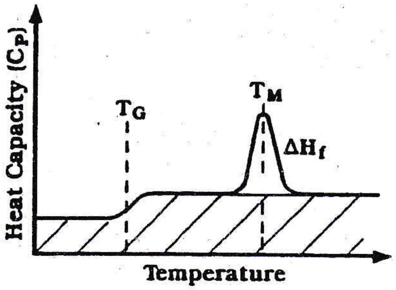
What is heat of fusion (melting) and does it relate to amorphous or crystalline polymers?

Participant's Notes:

STK 758

GE Plastics

Crystalline Melting



Heat of fusion ΔH_f is the amount of heat needed to melt a known amount of crystalline structure.

Participant's Notes:

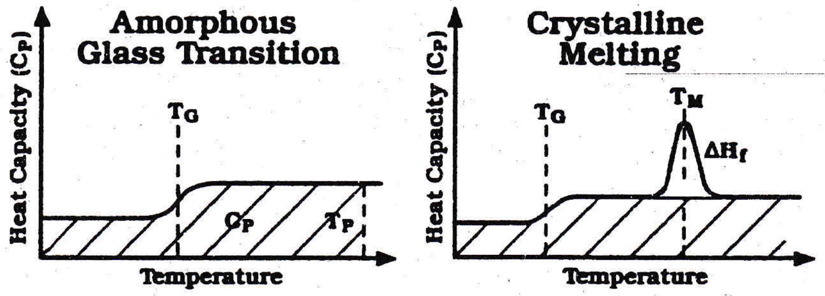
STK 759

What important thermal transition points does a heat capacity trace define?

Participant's Notes:

STK 760

Heat Capacity Trace



- The amorphous heat capacity trace points out the polymer T_G.
- The crystalline heat capacity trace points out the polymer's T_G and T_M.

Participant's Notes:

STK 761

GE Plastics

What are some of the ways we can attempt to control mechanical heating?

Participant's Notes:

STK 762

GE Plastics

Controlling Mechanical Heating

- Reverse Temperature Profile
- Reduce Back Pressure
- Slow Screw Speed
- Alter Screw Design

Participant's Notes:

GE Plastics

Module 8

Flowing and Forming Polymers

- What Is Flow?
- The Study of Flow
- Thermoplastic Processing

Participant's Notes:

Module 7

Performance Feedback

1. Describe how amorphous and crystalline polymers respond differently to heat energy. Relate these differences due to structure to: thermal transition points, temperature range for processing and amount of heat necessary for processing.
2. For a resin that you are currently working with: identify the thermal transition points, the temperature range for processing and the amount of heat necessary for processing.
3. Describe the effects of excessive heat.
4. Identify four strategies to reduce mechanical heat.
5. When given an actual or hypothetical situation of excessive mechanical heat, describe a realistic approach for dealing with this problem.