Characterization of Polymeric Materials by Thermal Analysis
Topics

- Introduction to DSC
- Introduction to TGA
- Applications
  - Amorphous Structure and the Glass Transition
  - Crystalline Structure
  - Thermosets
  - Thermal Stability and Kinetics
  - Heat Capacity
**DSC: The Technique**

- Differential Scanning Calorimetry (DSC) measures heat flow associated with structure (amorphous and crystalline) and changes in structure (transitions) of materials as a function of time and temperature in a controlled atmosphere.

- These measurements provide quantitative and qualitative information about physical and chemical changes in a material.

- The utility of DSC comes from the fact that all changes in structure involve the absorption or release of heat.
DSC: What DSC Can Measure

- Transition Temperatures
- Glass Transitions
- Melting/Crystallinity (J/g not %)
- Crystallization Time and Temperature
- Polymorphic Transformation/Stability
- Drug-Excipient Incompatibility
- Protein Denaturation
- Miscellaneous
  - Thermal/Oxidative Stability
  - Boiling Points
  - Purity
Possible Transitions in a DSC Curve

Glass Transition
*Crystallization
*Polymorphic Conversion
*Melting
*Polymorphic Conversion
*Denaturation
Crosslinking (Cure)
Oxidation or Decomposition
Some Q-Series DSCs and Cooling Devices
Tzero™ DSC Cell Schematic
New Sensor - Objectives

- Improve sensor flatness to reduce pan/sensor contact resistance variations
  - Reduce distortion due to thermal expansion difference between chromel area thermocouples and constantan platforms
  - Realize full benefit of Tzero sample pans – reduce pan contact resistance and variation
- Optimize thermocouple location
  - Thermocouple should not be in pan/sensor contact zone because inevitable variations in the magnitude and distribution of contact resistance reduces the repeatability of the differential temperature measurements
  - Locate thermocouple so that $\Delta T$ and $\Delta T_0$ measurements are unaffected by pan contact resistance variations
Diffusion Bonding Mechanism
Diffusion Bonded Transducer Construction Process
Why Diffusion Bonding?

- Optimum thermocouple placement
- Improved flatness of pan/sensor contact region by 6x
- No alloying of thermocouple by welding

Result – improved repeatability of signals, allowing full realization of advantages of Tzero technique
RESULT: THE PERFECT THERMOCOUPLE....

...IN
THE PERFECT POSITION
# TRIOS Running Queue

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**Control Panel:**
- Signal Name: Idle
- Value: 1
- Unit: 1

**General:**
- Temperature: 39.85°C
- Flange Temperature: 84.04°C
- Stability: 40.0°C

**Gas:**
- Flow: 50.0 mL/min
# TRIOS History View

## User Interface Overview

The TRIOS History View is a software interface designed to manage and display historical data related to experiments and samples. The interface includes a table view for detailed data entry and analysis. The application is accessible on a computer screen with a graphical user interface (GUI) that includes a main window displaying various controls and information.

### Interface Components

- **History View**:
  - The main frame displays a list of historical entries, with columns for `Date Time`, `Procedure Name`, `Sample Name`, `Mode`, `Test Type`, `Pan Type`, `Sample Pan No`, `Sample Size`, `Sample Pan Mass`, and `Reference`.

- **Date Time**:
  - Entries include dates and times from a specific period, indicating when experiments were conducted.

- **Procedure Name**:
  - Details the type of experiment conducted.

- **Sample Name**:
  - Identifies the specific sample used in the experiment.

- **Mode**:
  - Specifies the operational mode during the experiment.

- **Test Type**:
  - Indicates the type of test performed.

- **Pan Type**:
  - Details the type of pan used in the experiment.

- **Sample Pan No**:
  - The number of the sample pan.

- **Sample Size**:
  - The size of the sample.

- **Sample Pan Mass**:
  - The mass of the sample pan.

- **Reference**:
  - Notes or reference data related to the experiment.

### Additional Features

- **Calendar View**:
  - A section showing calendar entries, possibly for scheduling or planning purposes.

- **Notifications**:
  - A list of notifications, possibly alerts or error messages, with codes and descriptions.

### Tools and Controls

- **File Manager**:
  - An option for managing files associated with the experiments.

- **Control Panel**:
  - A section for configuring settings or parameters.

### Graphics and Images

The screen also includes graphical elements such as pie charts, bar charts, and other visual representations to aid in data analysis and visualization.

## Technical Details

- **System Configuration**:
  - The system is designed for Windows operating system.

- **Data Storage**:
  - Data is stored in a database or on local files.

- **Network Connectivity**:
  - The system can be accessed over a network, possibly for remote monitoring or collaboration.

### Purpose and Use

The TRIOS History View is used for recording and managing historical data from experiments, which can be crucial for scientific research, quality control, and regulatory compliance. It provides a comprehensive view of past experiments, allowing users to analyze trends, troubleshoot issues, and plan future experiments.

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**Note**: The specific values and details in the table view would need to be replaced with actual data for a complete and accurate representation of the TRIOS History View.
TRIOS Data Analysis Features
Discovery DSC Sensitivity

0.017 mg Indium, 1°C/min

Heat Flow (µW)

Temperature (°C)

16 µW peak height
Discovery DSC Sensitivity

0.229 mg Polystyrene, 5°C/min

Heat Flow (μW) vs. Temperature (°C)
Discovery DSC Sensitivity

0.229 mg Polystyrene, 5°C/min

~4 μW step change
Introduction to Thermogravimetric Analysis (TGA)
Topics

- TGA
  - The Technique
  - What TGA Can Measure
  - Importance of TGA in Materials Characterization
  - Instrumentation
TGA: The Technique

- Thermogravimetric Analysis (TGA) measures weight loss or gain as a function of temperature, time and atmosphere.

- TGA measurements are extremely useful in selecting experimental conditions for DSC experiments and for interpreting results.
What TGA Can Measure

- Temperatures of Weight Change
- Percent Weight Loss or Gain
- Decomposition Temperature(s)
- Decomposition Kinetics (MTGA™)
- Thermal/Oxidative Stability
- Unbound water or solvent
- Bound water or solvent (hydrate or solvate)
- Moisture adsorption/desorption (Sorption Analysis)
Importance of TGA

- Always start characterization of any new material with TGA. That data is often critical to the correct interpretation of DSC data. For example:
  - Is there unbound water or solvent?
    - Evaporation can look like melting
    - Water/solvent plasticize amorphous material which lowers and broadens Tg
    - If total volatile content (bound and unbound) exceeds 10% by weight, stainless steel hermetic pans will be required to heat above 130° C
What is the decomposition temperature?

- The initial stage of decomposition can be endothermic or exothermic.
  - If endothermic, it can appear as a melt
- Once decomposition begins, DSC provides no useful data about the structure of the drug
- Decomposition products can corrode the DSC cell and affect the baseline quality of future runs
- As a guideline, the upper temperature limit of the DSC experiment should not exceed the temperature of 5% weight loss due to decomposition
Thermogravimetric Technology

Conventional TGA

TGA Sorption Analyzer
The New Discovery TGA:
- Features TA Instruments:
  - Industry Leading Thermobalance
  - Innovative IR Furnace
  - Unmatched Autosampler

In Addition:
- A New Gas Delivery Module with either Standard 2-Gas or Optional 4-Gas for Switching/Blending Capabilities
- Improved Usability with the New Discovery User Interface
- New TRIOS Software with Instrument Control/Data Analysis in One Package
Baseline Accuracy and Repeatability
High Sensitivity for Small Weight Loss
Ballistic Heating

![Diagram showing temperature and derivative temperature over time with key points: 50.21 °C, 1.00 min; 1037.38 °C, 1.7 min; 1050.01 °C, 2.00 min; and 2008.32 °C/min.]}
Reliable Automation
Discovery TGA GDM

- Standard 2-gas switching or optional 4-gas switching/blending capabilities
- All purge gas information is data-logged and automatically saved into the TRIOS data file
4-Gas Blending GDM Schematic

Furnace

Balance / Base Purge

Sample

Blending Line

Air Cool Gas 1 Gas 2 Gas 3 Gas 4
Amorphous Structure
&
Glass Transition Studies
Amorphous Materials

- Amorphous Structure –
  - Randomly oriented molecules
  - No long-range order
  - Liquids, glassy or rubbery solids
  - Most polymers are either amorphous or semi-crystalline
Characterization of Amorphous Structure

- Glass Transition (Tg)
  - Due to amorphous (non-crystalline) structure
  - Due to macro-molecular motion (translational); i.e., the entire molecule is free to move relative to adjacent molecules.
  - Extremely important transition because the significant change in molecular mobility at Tg causes significant changes in physical and reactive properties.
Changes at the Tg

Polystyrene - Modes of Molecular Motion/Mobility

Temperature Below Tg
- lower Cp
- lower Volume
- lower CTE
- higher stiffness
- higher viscosity
- more brittle
- lower enthalpy

Glass Transition is Detectable by DSC
Because of a Step-Change in Heat Capacity

Exo Up

Heat Flow (mW)
Heat Capacity (J/g/°C)
Temperature (°C)

Polystyrene - Modes of Molecular Motion/Mobility

Translation
Rotation
Vibration

Universal V3.8A TA Instruments
What Affects the Tg by DSC?

- Heating Rate
- Heating & Cooling
- Aging
- Molecular Weight
- Plasticizer
- Filler

- Crystalline Content
- Copolymers
- Side Chains
- Polymer Backbone
- Hydrogen Bonding

Anything that affects the mobility of the molecules, affects the Heat Capacity, and in turn the Glass Transition
Effect of Heating Rate on the Tg

10.04mg PMMA

![Graph showing the effect of heating rate on the Tg of PMMA.](image)
Is it a Tg?

- If not sure if a transition is a Tg
  - Run Heat-Cool-Heat (H-C-H)
    - If transition is a Tg then it should be present on cooling curve and 2nd heat

- Run MDSC
  - A Tg will always show up in the Reversing Curve of a MDSC experiment

- Run TMA or DMA
Is this a Tg or a Melt?

![Graph showing heat flow versus temperature with a peak indicating a possible transition temperature.]
Now – Is this a Tg or a Melt?

Sample was annealed (aged) for 130 hours @ 135°C.

Polycarbonate 7.92mg
H-C-H @ 10° /min

Heat Flow (mW)

1st Heat

2nd Heat

Universal V4.3A TA Instruments
Measurement of Amorphous Structure

- The size of the glass transition is linearly proportional to the amount of amorphous structure in the sample.
- For small molecules, the glass transition is typically a sharp step and its size can be measured by standard DSC if the DSC has a straight baseline.
- For polymers, the glass transition is typically broader and becomes hard to measure as the crystalline content increases.
Quantification of Amorphous Structure

PET -- 9.43mg
MDSC .531/40@5

Change in Cp @ Tg is a measure of amorphous structure

% Amorphous = 0.145/0.353 = 41%
Partially Miscible Amorphous Phases

- If not miscible then Tg’s don’t shift
- If completely miscible then one Tg in the middle

ABS

ABS-PC

PC

ABS-PC Copolymer “Alloy”
Measuring Crystalline Structure
Semi-Crystalline Polymers

- Crystalline Structure –
  - Molecules arranged in well defined structures
  - Consists of repeating units
  - Polymers can have crystalline phases
    - Length of molecules prevents complete crystallization
- Semi-crystalline Polymers –
  - Both amorphous & crystalline solid phases
  - Examples are most common thermoplastics
    - Polyethylene, Polypropylene, etc
Melting – The process of converting solid crystalline structure to liquid amorphous structure
- Melting shows up as an endothermic peak in a DSC scan
- The energy required to melt the crystalline phase is proportional to the amount of crystalline phase
- In most cases sensitivity isn’t an issue with melting transitions
- Heating rate doesn’t effect the onset of melting (much), but will effect resolution
Definitions (cont.)

- **Crystallization** – The process of converting either solid amorphous structure (cold crystallization on heating) or liquid amorphous structure (cooling) to a more organized solid crystalline structure.

- **Enthalpy of Melting/Crystallization** - The heat energy required for melting or released upon crystallization. This is calculated by integrating the area of the DSC peak on a time basis.
Melting of Indium

For pure, low molecular weight materials (mw<500 g/mol) use Extrapolated Onset as Melting Temperature.
Melting of PET

For polymers, use Peak as Melting Temperature

Extrapolated Onset Temperature

Heat of Fusion

Peak Temperature

PET
6.79mg
10°/min

236.15°
52.19 J/g

249.70°
Heat-Cool-Heat of PET

Heat Flow (W/g)

Temperature (°C)

Cool

Second Heat

First Heat
Baseline Type

- Straight Baseline
- Sigmoidal Baseline

Note: Same Limits Used

- 106.84°C
- 89.87 J/g
- 105.82°C
- 96.77 J/g
- 108.95°C
- 108.90°C

Heat Flow (mW)

Temperature (°C)

Baseline Type

Heat Flow (mW)

Temperature (°C)
Crystallization

- Crystallization shows up as an exothermic peak in a DSC scan
- Crystallization is molten amorphous material changing to crystalline material upon cooling
- Cold-Crystallization is solid amorphous material changing to crystalline material upon heating
- Since crystallization is a kinetic transition, heating/cooling rate does effect the onset of crystallization, and will also effect resolution
Crystallization is a kinetic process which is typically studied either while cooling or isothermally, but can also be studied during heating (Cold-Crystallization). Differences in crystallization temperature or time (at a specific temperature) between samples can affect end-use properties as well as processing conditions. Isothermal crystallization is the most sensitive way to identify differences in crystallization rates.
Effect of Cooling Rate on Crystallization

Sample: PET
Weight: 10.66mg

Cooling Rates:
- 16°C/min
- 8°C/min
- 4°C/min
- 2°C/min

Glass Transition

Temperature (°C)

Heat Flow (mW)
Effect of Nucleating Agents

- Crystallization
- Melting

Comparison between POLYPROPYLENE WITH NUCLEATING AGENTS and POLYPROPYLENE WITHOUT NUCLEATING AGENTS.
What is Isothermal Crystallization?

- A Time-To-Event Experiment
Isothermal Crystallization

Heat Flow (mW)

Time (min)

Temperatures: 117.4°C, 117.8°C, 118.3°C, 118.8°C, 119.3°C, 119.8°C, 120.3°C
Characterization of Thermosets
Thermoset Materials

- A “thermoset” is a cross-linked polymer formed by an irreversible exothermic chemical reaction
  - A common example is a 2 part epoxy adhesive
- With a DSC we can look at the curing of these materials, and the Tg of full or partially cured samples
Thermosetting Polymers

- Curing reaction can be followed by monitoring a wide variety of physical properties including:
  - Heat of reaction
  - Heat capacity
  - Viscosity
  - Modulus
  - Others
Curing of a Thermosetting Material

20 Min Epoxy Cured in DSC
15.15mg @ 10°C/min

76.30°C
195.0J/g

116.07°C

Heat Flow (mW)

Temperature (°C)

Universal V4.3A TA Instruments
Effect of Heating Rate

Heat Flow vs Temperature graph with different heating rates:

- 1°C/min: Heat Flow = 0.5594 W/g, Heat Output = 323.9 J/g
- 2°C/min: Heat Flow = 0.9506 W/g, Heat Output = 315.1 J/g
- 5°C/min: Heat Flow = 1.972 W/g, Heat Output = 315.1 J/g
- 10°C/min: Heat Flow = 3.431 W/g, Heat Output = 320.5 J/g
- 20°C/min: Heat Flow = 5.792 W/g, Heat Output = 320.0 J/g
% Cure by DSC

- Need Heat of Reaction (Enthalpy) of unreacted material curing
  - Typically run uncured material in DSC
  - Run cured (partially cured sample) in DSC
Curing of “20-Minute” Epoxy

20 Min Epoxy Cured in DSC
15.15mg @ 10°C/min

Heat Flow (mW)

Temperature (°C)

116.07°C
76.30°C
195.0J/g

Exo Up Universal V4.3A TA Instruments
2nd Heat of Epoxy

Tg can be clearly seen. No residual cure exotherm visible.

20 min Epoxy Cured in DSC
15.15mg
Post-cure scan @ 10°C/min

Universal V4.3A TA Instruments
Epoxy Cured 48 Hours

1st Heat @ 10 °C/min
Cool @ 10 °C/min
2nd Heat @ 10 °C/min

5 Min Epoxy - 9.85mg
Cured 2 nights @ RT

Heat Flow (mW)
Temperature (°C)

Exo Up

Universal V4.3A TA Instruments
Reaction Kinetics

- The rate of reaction between the components is a function of time, temperature and formulation
- DSC can be used to measure how a formulation responds to time and temperature
- Data from DSC experiments can be applied to reaction models to predict reaction rates and required processing conditions
  - Borchardt & Daniels, single heat rate
  - ASTM E698, multiple heat rates
  - Isothermal, time to peak reaction rate
Epoxy Cure Kinetics

Thermoset Epoxy -- 5.536mg -- 10°C/min

Reaction Order: 0.95
Activation Energy: 82.9 kJ/mol
Log[pre-exp factor]: 10.34 log[1/min]
Heat of Reaction: 258.2 J/g
Standard Error: 0.0064 1/sec
Iso Conversion Plots

Thermoset Epoxy
Size: 5.536 mg
RT to 250° C @ 10° C/min
Thermal Stability
&
Kinetics
Thermal Stability

- Thermal Stability
  - Can be studied by multiple techniques
  - May be studied with inert or oxidizing atmospheres
  - TGA – Best choice
    - Weight loss
  - DSC
    - Change in heat flow (typically exothermic)
    - DSC cell can be contaminated
  - Can also see the effect in other techniques like DMA & TMA
TGA Profile In Nitrogen and Air

- First Step in Materials Characterization
- Look for:
  - Thermal Stability
    - Volatilization/Decomposition Temperature
  - Weight Loss Profile
    - Number of Steps
  - Residue
    - Char/Ash/Filler Presence
TGA Gives Upper Limit for DSC

PTFE 8.91mg
N₂ Purge @ 10° C/min

Decomposition products include Hydrogen fluoride!

Universal V4.3A TA Instruments
Thermal Stability of Polymers

Method Log:
1: Select gas: 1 - N2
   1: Ramp 20.00 ºC/min to 650.00 ºC
2: Select gas: 2 - Air
   3: Ramp 20.00 ºC/min to 1000.00 ºC

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Diagram:
- PVC
- PMMA
- PET
- LDPE
- PEEK

Weight (%) vs. Temperature (ºC)
Polyethylene Oxidation Temperature

Heat Flow (mW) vs. Temperature (°C)

Oxidation Onset Temperature (OOT)

-20
-10
0
10
20
50
100
150
200
250
300

245.22°C
125.54°C
Polyethylene Oxidative Induction Time

Oxidative Induction Time (OIT)
Effect of Pressure

Increased pressure of O2 decreases oxidation time

Sample is a Lubricating Grease

500 psig O2

Prog.: ISO 195°C

Heat Flow (mw)

Time (min)

7.54 min

20.15 min
As antioxidant level increases, time to oxidation increases

Sample is a Lubricating Grease with different levels of antioxidants
Latex paint @ various humidity’s and temperatures

- 10C & 90%RH
- 25C & 50%RH
- 40C & 10%RH

Paint Drying
Paint Drying at 25 °C and Various RH

Latex paint

Graph showing the weight change over time for different RH conditions:
- 25C & 90%RH
- 25C & 50%RH
- 25C & 10%RH
The rate at which a kinetic process proceeds depends not only on the temperature the specimen is at, but also the time it has spent at that temperature.

Typically kinetic analysis is concerned with obtaining parameters such as activation energy (Ea), reaction order (k), etc. and/or with generating predictive curves.
TGA Kinetics

- 1\textsuperscript{st} Order Kinetics based on Flynn and Wall method
- Lifetime Estimation based on Toops and Toops method
- PTFE tested at 1, 5, 10 and 20 deg/min
- Sample sizes constant
- Nitrogen purge
- Conversion levels selected at 1, 2.5, 5, 10 and 20%
Common Thermogram with TGA Scans

[Graph showing weight (%) vs. temperature (°C) with lines indicating different weight percentages (1.0%, 2.5%, 5.0%, 10.0%, and 20.0%)]
Log Heating Rate versus $1/T$

Check for linearity
Conversion Time versus Temperature

Conversion: 1.0%

E: 264.2 kJ/Mole
Log Z: 15.55 1/min
60 min half-life: 516.1

Percent Conversion versus Time

E: 264.2 kJ/Mole
Log Z: 15.55 1/min
60 min half-life: 516.1
Conversion: 1.0 %
Can be adjusted to known value

E: 264.2 kJ/Mole
Log Z: 15.55 1/min
60 min half-life: 516.1 hour
Conversion: 1.0 %
Heat Capacity
DSC Heat Flow

\[ \frac{dH}{dt} = \text{DSC heat flow signal} \]

\[ \frac{dH}{dt} = \frac{dT}{dt} \cdot \frac{\int \text{Sample Heat Capacity}}{\text{Sample Specific Heat}} \cdot \text{Sample Weight} \]

\[ \frac{dT}{dt} = \text{Heating Rate} \]

\[ f(T, t) = \text{Heat flow that is function of time at an absolute temperature (kinetic)} \]
What is Heat Capacity (Cp)?

- Heat capacity is the amount of heat required to raise or lower the temperature of a material.
- Cp is the absolute value of heat flow divided by heating rate (times a calibration factor).
- Most DSC’s do not measure absolute heat flow or heat capacity.
- Baseline subtraction is required on most DSC’s when measuring Cp.
- Q1000/Q2000 can measure Cp without baseline subtraction.
Heat Flow Due to Heat Capacity

10.04 mg PMMA

![Graph showing heat flow due to heat capacity with different rates of temperature change: 2.5°C/min, 5°C/min, 10°C/min, and 20°C/min.](chart)
Why is Heat Capacity Important?

- Thermodynamic property of material (heat flow isn’t)
- Heat capacity is a measure of molecular motion. Heat capacity increases as molecular motion increases.
  - Vibration – occurs below and above Tg
  - Rotation – polymer backbone and sidechains (in and above Tg)
  - Translation – entire polymer molecule (above Tg)
- Provides useful information about physical properties of the material as a function of temperature
Measuring Heat Capacity

- ASTM Method E1269
  - Requires 3 runs
    - Run Empty pans for baseline
    - Run calibrate (typically sapphire)
    - Run sample
  - Typical Method
    - Iso for 10 min
    - Heat @ 10° C/min
    - Iso for 10 min
  - Generally considered to be accurate & repeatable to within 5%
Conventional DSC Cp Measurement

\[ \text{Cp} = K \times \frac{H_{Fs} \pm H_{FMt}}{\text{Heat Rate} \times \text{wt}} \]

Where:
- \( K \) = Calibration constant
- \( H_{Fs} \) = Differential heat flow with sample
- \( H_{FMt} \) = Differential heat flow with empty pans
- \( \text{wt} \) = weight of sample
Conventional Heat Capacity of PET

Baseline
Sample
Calibration
Conventional Heat Capacity of PET

Heat Capacity & the Total Heat for Semicrystalline PET
DSC’s with advanced Tzero™ technology measure absolute heat flow:
- Baseline is flat
- Absolute zero heat flow value established as part of method
- By knowing absolute values of the heat flow and heating rate, heat capacity is calculated in real time and stored in data file
- Accuracy and precision is generally ± 2% with just single run measurements
Direct Cp Measurement

- Typical Method
  - Heat @10° C/min

- Sample Size ~10mg

- Lowest mass pans possible

- Generally considered to be accurate & repeatable to within 2-3%
Direct Heat Capacity

Average Value of 8 Runs at 20°C/min in a Hermetic Pan is 0.893 vs. a Theoretical Value of 0.902 J/g°C at 97°C. Total Range of Results Varied Less Than +/- 2%. Sample Was Replaced At The End of Each Run.
Direct Cp of Polyamide Resin

Temperature | Heat Capacity (J/(g·°C))
---|---
40 | 1.029
50 | 1.079
60 | 1.153
70 | 1.214
80 | 1.261
90 | 1.302
100 | 1.346
110 | 1.389
120 | 1.434
130 | 1.48
140 | 1.526
150 | 1.576
160 | 1.631
170 | 1.699

Polyamide Resin - 10.34mg
Heat @ 10°C/min
Cp by MDSC

- Cp can be measured directly in a single run.
- In MDSC, while you can look at 3 Cp signals, the Reversing Heat Capacity (Rev Cp) is the quantitative Cp.
- Long periods will give more accurate measurements.
- The Rev Cp constant should be calculated at the same period of the tests.
- Generally considered to be accurate & repeatable to within 1-2% (or better).
MDSC Conditions for Heat Capacity

- Heating Rate; isothermal up to 5°C/min
- Modulation Period
  - 120 seconds
- Modulation Amplitude; 0.5°C to 1.0°C
- Sample Size; 10-15mg
Heat Capacity by MDSC

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>Rev Cp (J/(g·°C))</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>0.4574</td>
</tr>
<tr>
<td>20</td>
<td>0.4686</td>
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<tr>
<td>30</td>
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<td>40</td>
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<tr>
<td>90</td>
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</tr>
<tr>
<td>100</td>
<td>0.543</td>
</tr>
<tr>
<td>110</td>
<td>0.5492</td>
</tr>
</tbody>
</table>

Epoxy Potting Compound - 42.53mg
MDSC 0.8/120@3°/min
What Affects Heat Capacity?

- Anything that effects the mobility of the molecules, affects the Heat Capacity
  - Amorphous content
  - Aging
  - Side chains
  - Polymer backbone
  - Copolymer composition
Effect of Amorphous Content on Cp

- Amorphous Cp is greater than Crystalline Cp
- Amorphous Content increases Specific Heat Capacity

Crystalline polymers contain more order and thus fewer degrees of molecular motion. Less molecular motion results in lower specific heat capacity.