Advanced Techniques and Strategies in Thermal Analysis and Calorimetry

(DSC, MDSC®, TGA, SA, and Microcalorimetry)

Thanks to
College of Textiles
North Carolina State University

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Program

9:00 – 9:45    Brief Introduction to Calorimetric and Gravimetric Technology

9:45 – 10:30   DSC and MDSC® Analysis for Materials Characterization

10:30 – 10:45  Break

10:45 – 12:00  Microcalorimetry and Sorption Analysis

A renaissance and revolution from TA Instruments
Thermal Analysis & Calorimetry

Thermal Analysis
- TGA & SA
- TMA
- DMA
- Scanning, Temperature-Induced Processes

Calorimetry
- DSC
- TAM
- ITC
- Solution Calorimetry
- Reaction Calorimetry
- Scanning or Isothermal
Calorimetric and Gravimetric Technology

Calorimetric Techniques:
• Differential Scanning Calorimetry (DSC)
• Modulated DSC® (MDSC®)
• Microcalorimetry (TAM) for small heat flows

Gravimetric Techniques:
• Thermogravimetric Analysis (TGA)
• Moisture Sorption Analysis (SA)
Differential Scanning Calorimetry (DSC)

- Measures the difference in heat flow rate between a sample and inert reference as both are subjected to the same linear temperature program.

- Primary Applications:
  - Glass Transition
  - Melting/Crystallization
  - Solid-Solid Transitions
  - Thermal Stability
Q-series DSC Schematic

Sample & Reference Platforms

Tzero™ Thermocouple
Some Possible Transitions in a DSC Curve

- Glass Transition
- *Crystallization
- *Polymorphic Conversion
- Crosslinking (Cure)
- *Melting
- *Polymorphic Conversion
- *Denaturation
- Oxidation or Decomposition
Modulated DSC® (MDSC ®)

• Measures the difference in heat flow between a sample and inert reference as both are subjected to a simultaneous linear and sinusoidal temperature program.
• Uses an MDSC® capable DSC
• Primary Applications:
  – Analysis of complex mixtures and formulations
  – Detection/measurement of weak glass transitions
  – Heat capacity measurement during kinetic processes
Note that temperature is not decreasing during Modulation i.e. no cooling

Modulate +/- 0.42 °C every 40 seconds
Ramp 4.00 °C/min to 290.00 °C
Average & Modulated Heating Rate; MDSC Does Not Require Cooling During Temperature Modulation

Note That Heating Rate is Never Negative (no cooling)
MDSC Separates Total DSC Heat Flow into Two Parts

MDSC® Data Signals and Transitions

\[
\frac{dH}{dt} = Cp \frac{dT}{dt} + f(T, t)
\]

Total = Reversing + Nonreversing

Transitions: Heat Capacity Enthalpic Recovery
Glass Transition Evaporation
Most Melting Crystallization

Thermoset Cure
Protein Denaturation
Starch Gelatinization
Decomposition
Some Melting
Denaturation of Soy Protein in Solution by MDSC®

Sample: 10% Soy Protein Solution
Size: 75.0000 mg
Method: MDSC 1/200@0.25
Comment: MDSC 1/200@ 25°C/min; HS

![DSC Graph showing denaturation temperatures](image-url)
Microcalorimetry: Thermal Activity Monitor (TAM)

• Measures heat absorbed or released by a sample as a function of time, temperature and environment

• Environmental factors can include solid, liquid or gas, voltage, light and other perturbations

• Primary Applications
  – HEAT of reaction, solution, interaction….
  – Stability and compatibility
  – Materials characterization
  – Biological processes
TAM III – an Integrated System

Monitor

Temperature controlled electronic box

Heat exchange by Peltier coolers

Oil expansion tank

Calorimeters

Keyboard

Computer

Power Supply

Circulation Pump
Calorimetric Range
Calorimeters of TAM III

- Nanocalorimeter  
  - Highest sensitivity
- Minicalorimeter  
  - Compact microcalorimeter
- Multicalorimeter  
  - Cluster of minicalorimeters
- 20 ml Microcalorimeter  
  - Larger samples
- Solution Calorimeter
- Titrations Calorimeters
Titration Ampoule

- Used for isothermal titration calorimetry (ITC) to study molecular interactions.
- Motor for stirring
- Gold propeller or turbine stirrer
- Stainless steel, Glass or Hastelloy
Precision Solution Calorimeter

- Heat of dissolution
- Amorphicity
- 25 and 100 ml
- Highest accuracy
- SolCal software for complete experimental control, data acquisition, data analysis and reports

Calibration heater
Thermistor
Sapphire tip
Stability and Compatibility Testing

Thermal stability of individual samples

Stability of solid mixture of A with B

Stability of A with B in gas or liquid form

Gas phase interaction

Interaction zone

Intimate exposure

By Lars-Gunnar Svensson, Celsius Materials CMK, Karlskoga, Sweden
Evaluation of Compatibility

A 50:50 mixture of two components A and B

If the heatflow curve of A+B (measured) differ from A+B (expected), this is an indication that the materials affect each other (are incompatible).
Compatibility of Wax and Mineral Wool

Thermogravimetric Analysis (TGA)

• Measures weight gain or loss as a function of time, temperature and environmental factors
• Purge gas is the most common factor which includes dry nitrogen, helium, air, oxygen, or gases with selected relative humidity (RH)

• Primary Applications
  – Free water or solvent
  – Bound water or solvent (i.e. hydrate or solvate)
  – Thermal stability and decomposition temperature
  – Moisture adsorption and desorption (i.e. sorption analysis)
Thermogravimetric Technology

Conventional TGA

TGA Sorption Analyzer
Q5000IR Autosampler
Q5000 SA – Humidity Chambers & Autosampler
Sealed Aluminum Pans and Punching

1. Home Position

2. Pre-Punching

3. Punching

Force Sensor

Punch
Free and Bound Solvent and Decomposition by TGA

Sample: Cold/Allergy Tablet
Size: 18.4890 mg
Method: Heat@10
Comment: N2 Purge=40/60mL/min.; TGA@10

TGA

1.135% Volatiles (0.2101mg)
2.356% Decomposition (0.4357mg)
Sorption Analysis of PVP by Humidity Steps @ 25°C

PVP
(polyvinylpyrrolidone)

Dwell times should be long enough to ensure equilibrium is reached.
Adsorption Isotherm of PVP

% Adsorption

% Weight Change

% Relative Humidity

Humidity Steps

42% at 80% RH
DSC and MDSC® Analysis for Materials Characterization
Background for This Topic

Difficulties often arise when using DSC to measure structure and properties of materials because of:

1. Lack of basic understanding of the nature of the material being analyzed and why the material is being analyzed
2. Presence of volatile and other components in the sample which effects structure and stability of the samples
3. Inadvertent decomposition sample during analysis
4. Disregarding the thermal history of the material
5. Relying on conservative tests that fail to recognize difference in samples, make full use available data, or realize the technical objective
6. Underutilizing complimentary analytical techniques
1. Know why the analysis is being conducted. What are the primary (and secondary) objectives?

2. Start characterization of any new material with TGA.

   • TGA data is often critical for DSC when selecting experimental conditions and interpretation of data.
   • For example: Is there unbound water or solvent?
     - Evaporation can look like melting
     - Water/solvent plasticize amorphous material which lowers and broadens Tg
     - Do volatiles need to be retained during the DSC experiment? The answer will effect the selection of the DSC pans and conditions.
3. The TGA results also provide information on the thermal stability of the material. What is the decomposition temperature?

• The initial stage of a decomposition can be endothermic or exothermic.
  – If endothermic, it can appear as a melt
• Once decomposition begins, DSC provides limited useful data unless the objective is to study the material stability and degradation
• Decomposition products can corrode the DSC cell and affect the 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
Recommended TGA Initial Experimental Conditions

- Sample Size: 2-5mg (10mg if large quantity of material available)
  - Larger samples increase weight loss accuracy and increase sensitivity to detect minor components
  - Use of smaller samples requires a TGA with a very stable baseline
  - Resolution of overlapping weight losses is improved by maximizing sample surface area
  - Test environment (laboratory) should have minimal vibration and no rapid pressure changes in order to improve signal-to-noise ratio and eliminate artifacts in data
Recommended TGA Initial Experimental Conditions

- Heating Rate; 10° C/min
  - Slower heating rates often increase resolution of overlapping weight losses
  - If improved resolution is desired on subsequent runs, consider use of Hi-Res TGA which automatically reduces the heating rate during periods of weight loss
  - Faster heating rates reduce test time but remember, decomposition is a kinetic process that shifts to higher temperature as heating rate is increased (shift is function of activation energy)
  - 10°C/min is approx. average of 2 & 20°C/min that will be recommended for DSC
Interpreting Results

Some Examples of TGA Data
TGA Analysis of Acetaminophen Tablet

Sample: Acetaminophen  
Size: 22.3920 mg  
Method: Ramp

- Heating Rate of 10°C/min
- Decomposition Begins Near 180°C
- Approx. 1.5% Volatiles
4. Disregarding the thermal history of the material

- Thermal (and mechanical) history can drastically alter the results obtained by DSC.
- Knowing the thermal history or using the DSC to impose a known thermal history commonly practiced. A **Heat-Cool-Heat** strategy examines the provided sample with its given thermal history, uses the cool for additional data and to impose a known thermal history and uses the second heat to examine the sample with a known thermal history as imposed by the cool.
- **MDSC®** enhances sensitivity and provide additional information which is not available from traditional DSC. A strength of **MDSC®** is separate the properties of the material from its thermal history. Thermal and mechanical relaxations are kinetic events; so information on the thermal history of the sample appears in the non-reversing thermogram.
5. Relying on conservative test can fail to recognize difference in samples or realize the technical objective

- The quality of DSC results are enhanced by proper selection of experimental conditions, and approach and analysis techniques
- MDSC® enhances sensitivity and provide additional information which is not available from traditional DSC. For example:
  - Detection of weak transitions or heat capacity baseline
  - Determination of heat capacity at the same temperature where kinetic events occur in the sample
- Multiple run DSC strategies provide information not available from a lone DSC run (e.g. kinetics, polymorph characterization, phase diagrams)
- Reliance on advanced data treatments (e.g. van’t Hoff calorimetric purity, heat capacity, Gibbs energy diagrams)
Interpreting Results

Effect of DSC Conditions on Results
Use of TGA to Determine Volatile Content and Assist With Interpretation of DSC Data

Sample: Drug A Monohydrate
Size: 15.1740 mg
Method: R10
Comment: N2 Purge=40/60mL/min.; TGA@10

4.944% Dehydration of 5% Monohydrate (0.7501 mg)
Pan Selection Distinguishes Melting and Evaporation

Effect of Hermetic (sealed) vs. Non-Hermetic Pan on DSC Results for Drug A Monohydrate

Endothermic Peak Due to Evaporation of 5% Water Seen in the TGA Data

- Sample: Drug A Monohydrate
- Sample Size: Approx. 1 mg
- Pan Type(s): Hermetic, with and without pinhole
- Heating Rate: 10/min

Exo Up
MDSC Shows Increase in Cp During Evaporation of Water from Dehydration of 5% Hydrate

Sample: Crystalline Drug Monohydrate
Size: 3.7500 mg
Method: MDSC 159/60@1

Note that heat capacity actually increases with 5% dehydration.
Data Presentation and Scaling Can Obscure Results

Sample: Acetaminophen
Size: 13.6800 mg
Method: MDSC 1/50@2
Comment: MDSC 1/50@2

DSC

Average Heating Rate of 2°C/min

19.41°C(H)
-0.27mW

0.2J/g

141.9°C
-0.05mW

It is sometimes necessary to accept lower resolution on some transitions in order to have enough sensitivity for others.
Amorphous Content and the Glass Transition
Characterization of Amorphous Structure

• Glass Transition
  – Due to amorphous (non-crystalline) structure
  – A step change in heat capacity at the glass transition temperature (Tg).
  – Observed on both heating and cooling.
  – 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.
Heat Flow, Heat Capacity, and Other Physical Properties Change at the Glass Transition Temperature

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

- Modes of Molecular Motion/Mobility
  - Vibration
  - Rotation
  - Translation

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

Polystyrene
Glass Transition (cont.)

• Reporting the Glass Transition Temperature (Tg)
  – Tg is always a temperature range and never a single temperature
  – When reporting a single temperature, it is necessary to state;
    ▪ What point in the step change (onset, midpoint, end etc) is being measured
    ▪ The experimental conditions used to measure Tg; such as technique (DSC, DMA, TMA etc.), heating rate, sample size or weight, modulation conditions, etc.
DSC Glass Transition Analysis

Sample: Polystyrene
Size: 9.6700 mg
Method: DSC q2, 5, 10 & 20
Comment: DSC at Variable Heating Rates; T4P Signal
Glass Transition (cont.)

- Since the Glass Transition is a relatively low energy transition and is due to only amorphous structure in the sample, Tg is often hard to detect in semi-crystalline samples. To increase sensitivity:
  - Use larger (>10mg) samples and higher (>10C/min) heating rates
  - Use MDSC® for complex samples
  - Quench cool sample from a temperature above the melt point to maximize amorphous structure
Effect of Thermal History on the Structure of Acetaminophen

Sample: Acetaminophen, Pinhole Pen
Size: 10.2500 mg
Method: R10
Comment: DSC@10C/min, Dry Orig, after Quench and 1C/min Cool

DSC

- Cold Crystallization of Amorphous Structure
- Tg after 1C/min cooling
- Tg after quench cooling
- Solid-Solid Polymorphic Transition?
- Melting of Crystalline Structure

Heat Flow (W/g)

Temperature (°C)

Exo Up
Absorbed Moisture Acts as a Plasticizer

Sample: Amorphous Sucrose; some Water
Size: 4.2000 mg
Method: DSC@ 20
Comment: DSC@ 20; Crimped Pan w/Pinholes; 2 heats

Tg of Dry Sucrose ≈ 68°C

Note: Tg Shifted by Over 40°C Due to Loss of Water
Amorphous Content of Highly Crystalline Lactose

TAM Data

Sample: Acetaminophen, Pinhole Pen
Size: 10.2500 mg
Method: R10

DSC

% Amorphous = \( \frac{0.03}{0.55} = 6\% \)
Characterization of Crystalline Structure
Crystallinity

Definitions

• 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

• Crystal Perfection – the process of small, less perfect crystals (metastable) melting at a temperature below their thermodynamic melting point and then (re)crystallizing into larger, more perfect crystals that will melt again at a higher temperature
Change in Crystallinity While Heating

Quenched PET
9.56mg
10°C/min

134.63°C
127.68°C
0.6877 J/g
230.06°C
71.96 J/g
Crystallization

- Crystallization is a kinetic process which can be studied either while cooling, isothermally, or heating
- 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 detect differences in crystallization rates
- Crystallization is a two step process of nucleation followed by crystal growth
Effect of Nucleating Agents

POLYPROPYLENE WITH NUCLEATING AGENTS

POLYPROPYLENE WITHOUT NUCLEATING AGENTS

crystallization

melting
What is Isothermal Crystallization?

- A Time-To-Event Experiment

Annealing Temperature

Melt Temperature

Isothermal Crystallization Temperature

Zero Time
Isothermal Crystallization

Polypropylene
Multiple Run DSC Strategies

Multi-run experimental approaches for polymorph, melting verification, thermal stability, imposed thermal history, kinetics ....
Melting of Crystalline Drugs is Often More Complex Than It Initially Appears

Sample: Anhydrous Drug A
Size: 1.1400 mg
Method: DSC@10
Comment: DSC@10

DSC

153.64°C 24.94 J/g
159.63°C 40.27 (65.21) J/g
155.42°C
160.78°C

DSC@10°C/min;
2 Melting Peaks Seen

Heat Flow (mW)

Temperature (°C)
Low Heating Rates Often Show More Crystal Forms

Sample: Anhydrous Drug A
Size: 1.2300 mg
Method: DSC@1
Comment: DSC@1

DSC

152.18°C
153.76°C
159.99°C 65.08J/g
160.76°C
174.99°C

DSC@1°C/min;
3 Melting Peaks Seen
High Heating Rates Obscure or Suppress Crystalline Transformation
Comparison of Different Heating Rates on the Polymorphic Transformation in Anhydrous Drug

Effect of Heating Rate on Transitions in a Pharmaceutical Drug

All Curves Scaled Based on Heating Rate and All approx. 65J/g
Effect of Heating Rate on PET Melting

![Graph showing the effect of heating rate on PET melting. The graph plots heat capacity (J/g/°C) against temperature (°C) for heating rates of 10°C/min, 50°C/min, 100°C/min, and 150°C/min. The graph indicates a significant melt peak at around 240°C for the highest heating rate.]
Melting is a Thermodynamic Property
Not Dependant on Heating Rate

Effect of Heating Rate on the Melting Point of Phenacetin
(No Decomposition)

Hermetic Aluminum Pan
Approx 1.5mg Sample

Onset of Melting Shifts by 0.3°C
Over Heating Rate Range of 1-20°C/min
for Sample That Does Not Decompose
Decomposition and Volatilization are Kinetic Processes Shift With Heating Rate
Advanced Data Treatments

Calorimetric purity, heat capacity, Gibbs energy diagrams, ....
Calorimetric Purity

An absolute method
Effect of Impurities on Melting

Effect of p-Aminobenzoic Acid Impurity Concentration on the Melting Shape/Temperature of Phenacetin

- 99.3% Pure
- 100% Pure
- 96.0% Pure
- 95.0% Pure
- NBS 1514 Thermal Analysis Purity Set

Approx. 1mg Crimped Al Pans 2°C/min
Van't Hoff Purity Calculation

Purity: 99.53mol %
Melting Point: 134.92°C (determined)
Depression: 0.25°C
Delta H: 26.55kJ/mol (corrected)
Correction: 9.381%
Molecular Weight: 179.2g/mol
Cell Constant: 0.9770
Onset Slope: -10.14mW/°C
RMS Deviation: 0.01°C
Heat Capacity

An absolute thermodynamic property
Why is Heat Capacity Important?

• Absolute thermodynamic property (vs. heat flow) used by engineers in the design of processing equipment

• Measure of molecular mobility
  – $C_p$ increases as molecular mobility increases.
  – Amorphous structure is more mobile than crystalline structure

• Provides useful information about the physical properties of a material as a function of temperature
Specific Heat Capacity (Cp)

• Heat capacity is the amount of heat required to raise the temperature of a material by 1°C

• True Heat Capacity (no transition) is completely reversible; the material releases the same amount of heat as temperature is lowered by 1°C

• Specific Heat Capacity refers to a specific mass and temperature change for a material (J/g/°C)
Does DSC Measure Heat Capacity?

- DSC or MDSC® do not measure heat capacity directly. They measure heat flow rate which can be used to calculate heat capacity which is more appropriately called apparent heat capacity
  - DSC calculated Cp signals include all transitions because the heat flow signal is simply divided by heating rate (an experimental constant) to convert it to heat capacity units
  - A true value of Cp can only be obtained in temperature regions where there are no transitions
Calculating Heat Capacity (Cp)

- Depending on the DSC that you have there are three different ways to calculate Cp

1) Three Run Method – ASTM E1269
   - Applicable to all DSC’ instruments

2) Direct Cp – Single Run Method
   - Applicable to Q1000 / Q2000 only

3) MDSC® - Single Run Method
   - Any TA Instruments DSC w/ MDSC option
Cp by the Three Run Method

• Generally, three experiments are run in a DSC over a specific temperature range
  – Empty pan run
  – Sapphire run
  – Sample run
Calculating Cp by Standard DSC

- Three experiments are run over a specific temperature range
  - Initial 5 minute isothermal at start
  - Use 20°C/min heating rate
  - Final 5 minute isothermal at end

1. Empty pan run
   - Match pan/lid weights to ± 0.05 mg
   - Used to establish a reference baseline
Calculating Cp by Standard DSC

2. Sapphire run
   – Used to determine calibration constant
   – Use same matched weight of pan/lid as before
   – Typical weight is 20 – 25 mg

3. Sample run
   – Typical weight is 10 – 15 mg
   – Use same matched weight of pan/lid as before
Cp by Traditional DSC – 3 Run Method

Heat Flow

Baseline Run

Sample Run

Calibration Run

Heat Flow (mW)

Temperature (°C)

Time (min)
Cp by Traditional DSC – 3 Run Method

Cp & Total Heat for PET

Heat Capacity (J/g/°C)

Temperature (°C)

50.00 °C 1.161 J/g/°C

50.00 °C 1.609 J/g/°C

150.00 °C 174.6 J/g

280.00 °C 454.6 J/g

280.00 °C 1.924 J/g/°C

454.6 J/g

34.94 J/g
Heat Flow w/ Different Heating Rates

Heat Flow Signals Increase in Size with Increasing Heating Rate
Benefit of Plotting Heat Capacity

Heat Capacity Signals Are Normalized for Heating Rate and Permit Comparison of Experiments Done at Different Heating Rates

Remember, DSC and MDSC Cp signals are really Apparent Cp signals; crystallization and melting are latent heats, not Cp
Heat Flow & Cp Signals

Polypropylene
Size: 9.21 mg
DSC Cycle @ 10degC/min
Figure 40; The Change in Enthalpic Recovery with Storage Time Can be Easily Measured by MDSC®

Sample: Polystyrene
Size: 14.02 mg
Method: Anneal at 85°C for various times
MDSC 2°C/min
Specific Heat Capacity

• MDSC® & Tzero™ DSC have the ability to calculate a heat capacity signal directly from a single run.

• Benefits of using a heat capacity instead of heat flow signal include:
  – Heat capacity is a thermodynamic property
  – The ability to overlay signals from samples run at different heating rates
  – The ability to overlay signals from heating and cooling experiments
Direct Cp from a Q1000 / Q2000

Absolute integral calculates total heat

Latent Heat of Melting is Not Heat Capacity

Latent Heat of Crystallization is Not Heat Capacity

Heat Capacity (Single Run)

Running Integral

Heat Capacity (J/g/°C)

Temperature (°C)

Heat Capacity (J/g)

Integral (J/g)

275.00°C
530.8J/g

135.54°C
0.7311J/g

250
200
150
100
50
0

Universal V3.8A TA Instruments
Specialized PDSC Techniques

Photo DSC and Pressure DSC
Photopolymer Cure by PCA

Cure of a Photopolymer by PCA

Method Log:
1: Equilibrate at 35.00 °C
2: Isothermal for 1.00 min
3: Light: on @ 20mW/cm²
4: Isothermal for 5.00 min
5: Light: off
6: Isothermal for 2.00 min
7: End of method
Photo-cured Thermoset

Figure 2
Adhesive A Flash Curing
Increased pressure of O2 decreases oxidation time.
With ambient pressure, curing is not visible due to volatization of water. Water comes from the condensation reaction during the curing of the phenolic.
6. Underutilizing complimentary analytical techniques

- DSC results (or results from other techniques) cannot be viewed in a vacuum.
- As TGA guides the execution of DSC analysis.
- The results from other techniques should be examined for consistencies and apparent inconsistencies.
- Apparent inconsistencies in the cumulative results warrant further investigation to reconcile discrepancies.
- Some complimentary techniques include:
  - Other thermal analysis techniques
  - XRD -- Calorimetry
  - MS -- Elemental analysis
  - Microscopies (Polarized light, SEM)
  - Spectroscopies (FTIR, Raman)
  - Chromatographies (UPLC®, GC, SEC)
Advances in Thermogravimetry and Moisture Sorption Analysis
Advances in Thermogravimetry

- Advanced thermobalance
- Infrared heating TGA
- Importance of moisture adsorption
- Moisture sorption analyzers
Advanced Thermobalance
Thermobalance Performance

- Baseline drift of <10 µg
- Excellent baseline reproducibility
- Sensitivity of < 0.1 µg
- Great for detection of low level component and small mass losses
- Free of electrostatic effects

A new standard for thermobalance performance
Infrared Heating
Thermogravimetric Analyzer
Infrared Furnace Design Features

- High energy efficiency: 500 W at 1200 °C
- Tubular halogen lamps (4) – user replaceable
- Reflector: elliptical; water-cooled, gold-plated; polished
- Silicon carbide absorber for uniform infrared heating
- Internal components: quartz liner, upper / lower heat shields easily removed for cleaning
- Horizontal purge gas system w/ 3 mass flow controllers
- New plate style thermocouple
- Heated adapter for evolved gas analysis
Infrared Furnace - Horizontal Section

- Magnetic field coil
- Heated EGA adapter
- Sample pan and thermocouple
- Silicon carbide absorber

Key Components:
- Quartz halogen lamp (4)
- Purge gas inlet
- Elliptical reflector

Diagram elements correspond to the list.
Infrared Furnace Performance

- Ambient to 1,200 °C operating range
- Linear heating rates of 0.1 to 500 °C/min
- Over 1,000 °C/min in ballistic heating
- Rapid cooling: 1200 to 50°C <10 min w/ forced air or N2
- Evolved gas analysis capability
- Advanced resolution enhancement techniques
- Vacuum operation (10^(-2) torr)

Really sets records for TGA furnace operation
Advance Balance and Infrared Heating Provides

Major New Performance Features

- Unmatched baseline flatness and reproducibility
- Highest linear heating rates of 0.1 to 500°C / min
- Larger autosampler with sealed pan punching mechanism
- Unique integrated electromagnet coil for calibration

Significant Benefits

- Better detection of minor weight losses
- Superior measurement of residues
- Track processes with large temperature changes
- Productivity improvement
- Autosampler analysis of environmentally sensitive materials (i.e. moisture, volatiles, oxygen, light)
High Sensitivity Volatiles Analysis

2.4 mg PET
10°C/min

0.2162% Volatiles (0.005198mg)
High-Heating Rate TGA (1 of 2)

- 60.09% Polypropylene (2.736mg)
- 40°C/min: 60% polymer
- 500 °C/min: 40% calcium carbonate
The New Generation of Multichannel Microcalorimetric System from TA Instruments
Thermal Activity Monitor - TAM

• TAM represents a range of products from TA Instruments used for microcalorimetric measurements

• TAM III is the new generation multichannel microcalorimetric system
  – Highest sensitivity calorimetric measurements (nanowatt scale)
  – Highest level of temperature precision (0.0001°C)
  – Wide range of applications
    ▪ Pharmaceuticals
    ▪ Material Science
    ▪ Life Science

• Complementary technique to TA Instruments existing technology
Calorimetric Range

-12 -10 -8 -6 -4 -2 0 1 2 3

1 pW 1 nW 1 μW 1 mW 1 W
TAM III

- High sensitivity and baseline stability
- Isothermal, scanning or step isothermal mode
- Different heat flow measuring modes
- High sample throughput
- High flexibility - one instrument can be used for many different applications
General features of TAM III

- Temperature range: 15→150°C
- Easy to use
- Outstanding sensitivity and long-term stability
- High sample throughput
- Multi functional
- Different measuring modes
- Various operating modes
- A range of calorimeters
- Various sample handling systems
- Auxiliary equipment
- Network identity – IP address
Easy to Use

• TAM III is simple to use.
• Usually requires very little sample preparation
• The measurement is continuous so there are no breaks in the data collected.
• A dedicated software package, TAM Assistant™ performs all sample set up and data acquisition.
Outstanding Sensitivity

• TAM III is excellent for Isothermal Titration Calorimetry

• In Power Compensation mode TAM III can detect heat pulses less than 1 \( \mu \)J produced by internal electric heaters (1 \( \mu \)W/1 sec).
High Sample Throughput

• TAM III is a multichannel microcalorimetric system offering up to 48 experiments to be performed.
• TAM III is ideal for research purposes as well as for large scale screening.
Multi-Functional

• TAM III is a flexible system which can be configured for a variety of applications.
• New functions or measuring capacity is easily obtained by adding:
  – Calorimeters
  – Sample handling systems
  – Auxiliary equipment
Heat exchange by Peltier coolers

Circulation Pump

Oil expansion tank

Monitor

Temperature controlled electronic box

Computer

Power Supply

Calorimeters

Keyboard

TAM III – an Integrated System
Thermostat

• Controls the operating temperature during a calorimetric measurement.
• Contains one or more calorimeters
• Three models available
  – TAM III
  – TAM 48
  – TAM AIR
TAM III Thermostats

• The heart of TAM III
• Standard thermostat for:
  – 4 ml Nanocalorimeters
  – 4 ml Multicalorimeters
    (6 x 4 ml Minicalorimeters)
  – Flow/Mix calorimeters (pending)
  – 20 ml Microcalorimeter
  – Solution Calorimeters
• 48 channel version for:
  – Minicalorimeters
  – (hold up to 48 calorimeters)
• Temperature accuracy:  ±0.1°C
• Temperature precision: < ±0.0001°C
Calorimeters of TAM III

- Nanocalorimeter
  - Highest sensitivity
- Minicalorimeter
  - Compact microcalorimeter
- Multicalorimeter
  - Cluster of minicalorimeters
- 20 ml Microcalorimeter
  - Larger samples (e.g. battery)
- Solution Calorimeter
Measuring Modes of TAM III

• Heat flow (high sensitivity, longer time scales)
  – In case of any thermal activity in the sample (exothermic or endothermic) heat will be exchanged with the surroundings through the heat detector.
  – The signal from the detector reflects the rate of heat production by the sample (also referred to as “Heat Flux”)

• Power compensation (high resolution, shorter time scales)
  – A constant electric power is supplied to both sample and reference calorimeters continuously.
  – In case of any thermal activity in the sample the power to the sample is reduced or increased to keep the total heat flow to the sample the same.
  – From the change in the electric power the rate of heat production of the sample is calculated.
Nanocalorimeter

• Highest sensitivity
• Integrated with electronics
• Only choice for
  – ligand binding
  – molecular interactions
• Used with Micro Reaction System
  – Titration ampoule
  – RH Perfusion ampoule
  – Perfusion ampoule
  – Combinations of ampoules
Minicalorimeter

- 1 or 4 ml volume
- TAM III 48 channel version
- TAM III four channel version (Multicalorimeter)
- Micro Reaction System can be used
Minicalorimeter

- Sample Ampoule holder
- Thermopiles
- Reference Ampoule holder
- Outer Steel Cylinder
- Heat Sink
Multicalorimeter

- For increased measuring capacity & productivity
- Consists of 6 x 4 ml Minicalorimeters
- 4 Multicalorimeters can be used with TAM III to provide 24 simultaneous measurements
Micro Reaction System

- Perfusion ampoule
- RH Perfusion ampoule
- Titration ampoule
- Combinations of above
Perfusion ampoule

- For gas and liquid perfusion experiments
- Gas Flow Control kit is used for control of gas composition and flow rate
- A Peristaltic Pump is used for control of liquid flow rate
- Stainless steel, Glass or Hastelloy
RH Perfusion ampoule

• For control of the relative humidity or vapor pressure of suitable solvents other than water.
• Gas Flow Control kit is used for control of gas composition and flow rate.
• Humidity can be changed step-wise or linearly with time.
• Stainless steel, Glass or Hastelloy
Titration ampoule

• For isothermal titration calorimetry – the study of molecular interactions.
• Motor for stirring
• Gold propeller or turbine stirrer
• Stainless steel, Glass or Hastelloy
20 ml Microcalorimeter

- 20 ml volume
- For large samples,
  - e.g. batteries
- For experiments requiring a large gas phase above the sample
- 20 ml Micro Reaction System
  - Including micro solution ampoule
Precision Solution Calorimeter

- Heat of dissolution
- Amorphicity
- 25 and 100 ml
- Highest accuracy
- SolCal software for complete experimental control, data acquisition, data analysis and reports
Precision Titration Calorimeter

- Heat of dissolution
- Thermodynamic parameters of binding reactions
- Amorphicity
- 25 and 100 ml
- Highest accuracy
- SolCal software for complete experimental control, data acquisition, data analysis and reports
Applications

- TAM III can be used to study almost all kinds of physical and chemical processes in:
  - Material Sciences
  - Pharmaceutical Sciences
  - Life Science
  - Chemistry and Physical Chemistry
TAM Applications: Pharmaceuticals

- Stability & Shelf Life
- Pharmaceutical Compatibility
- Amorphicity & Crystallinity
TAM could detect stability data for Benzoyl peroxide down to 20°C which couldn't be done with UV/Vis spectrophotometry. The data were obtained within 16 hours revealing a first order rate constant of $10^{-9}$ s$^{-1}$ which is equivalent to a half life of 22 years.

Amine-Lactose Interactions

One approach to perform excipient compatibility screening is to add water to the powder mixture. The graph shows the response of an amine-lactose interaction at different temperatures with 20% water added.

Using Hydrostats


Moisture Induced Recrystallization
Amorphicity by Solution Calorimetry

Hogan & Buckton,
TAM Applications: Material Science

- Stability Testing
  - Detergent
  - Energetics
- Compatibility
- Setting Time of Cement
Stability of Sodium Percarbonate
Compatibility Between Wax and Mineral Wool

Setting Time of Cement

Dr. Sandberg, Grace Construction Products, US (2002)
TAM Applications: Life Science

• Drug Efficacy
• Purification of Proteins
• Molecular Interactions
• Microorganism Detection
Drug Efficacy

Flow calorimetry: Leukemia (T-lymphoma) cells exposed to the anti-cancer drug methotrexate. The final drug concentrations were (a) 0, (b) 0.2, (c) 0.5, (d) 1.0, (e) 2.0, (f) 4.0µM (ref 6).

Hydration Calorimetry

Dry Lysozome Exposed to an RH Ramp

Microorganism Detection

Microcalorimetry - A Novel Method for Detection of Microorganisms in Platelet Concentrates and Blood Cultures. Andrej Trampuz, Simone Salzmann, Jeanne Antheaume, Reno Frei, A.U. Daniels University of Basel & University Hospital Basel, Switzerland
TAM-Summary

• The TAM III is a powerful new addition to the TA Instruments product line
• Microcalorimetry complements existing TA products such as sorption analysis and MDSC
• The applications or microcalorimetry are broad and diverse
• Stay tuned for more exciting and interesting applications and product information regarding the TAM III and microcalorimetry

Questions?
IMPORTANCE OF MOISTURE ADSORPTION
Why is Moisture Sorption Analysis Important?

- Water is everywhere!

- Water affects properties of virtually all materials: polymers, foods, organics, inorganic, and pharmaceuticals.

- Material properties must be tailored for realistic RH conditions.

- Moisture sorption often effects processing, transportation, storage, packaging, stability, and end use performance.
Importance of Moisture Measurements

➢ Polymers
  ▪ Effect on the glass transition
  ▪ Water soluble polymers (PVP, PVOH)

➢ Foods
  ▪ Storage stability
  ▪ Texture
  ▪ Deliquescence

➢ Pharmaceuticals
  ▪ Polymorphic forms - legal implications
  ▪ Solubility/dissolution rate - bioavailability
  ▪ Stability - shelf life
  ▪ Ease of manufacture
Effect of Moisture on $T_g$ for Nylon 6,6

Food Texture Dependency on Moisture Content

Features of the Sorption Analyzer

• Temperature - Controlled Thermobalance
• Symmetric Thermoelectric Furnace
• Symmetric Humidity Control Chamber
• Integrated Autosampler
• Sorption-specific Algorithms
• Compact Integrated Design
Schematic of a Sorption Analyzer
Moisture Sorption Experiment

➢ Isotherm or isohumidity experiment?
➢ Humidity calibration using salt / salt solution
➢ Determine “dry” sample weight
➢ Analyze material
➢ Program increasing isotherms or isohumidities
➢ Program decreasing isotherms or isohumidities
➢ Generate isotherm or isohumidity plot

Moisture sorption experiments takes TIME!
Typical Moisture Sorption Tests

- Sorption Isotherm
  - Isothermal Temperature, Stepped Humidity
- Adsorption/Desorption
  - Isothermal Temperature, Step Humidity Up-Down
- Isohume
  - Isothermal Temperature, Constant Humidity
- Humidity Ramp
  - Isothermal Temperature, Ramp Humidity
- Custom Methods
  - Variety of segments including temperature ramp
Commonly material used for sorption verification.
Polyvinylpyrrolidone Adsorption Isotherm

Adsorption Isotherm of PVP at 25°C

% Weight Change

% Relative Humidity

% Adsorption
Deliquescence Salt – LiCl at 25 °C

Deliquescence point at 11% RH
Urea – Humidity Ramp Up then Down

Ramp Experiment

Urea @ 25°C

75.50%
Amorphicity: Generic Drug at 25 °C
Quantification of Amorphous Content

Micronized Lactose

Increase in weight due to trapped moisture in new crystal lattice.

0% RH

25% RH

80% RH

0% RH

25% RH

80% RH

Increase in weight due to trapped moisture in new crystal lattice.
Pharmaceutical Tablets (Aspirin)
The Joys of Paint Drying
Summary: Sorption Analysis

• Sorption Analysis is a valuable analytical technique with a wide range of applications
• A high-performance sorption analysis system
  – Precise Ambient Temperature/RH control (step, ramp, isohume)
  – Dedicated experimental templates
  – Integrated SA-specific analyses
• Sorption Analysis is a complementary technique to thermal analysis, but should be performed on dedicated instrumentation for optimal results
Who benefits from Sorption Analysis?

➤ Any industry where moisture has a significant influence on product end-use performance

➤ Industries which include:
  - Pharmaceutical
  - Foods
  - Polymers
  - Textiles
  - Paper
  - Forest Products
  - Consumer Products
  - Minerals/Concrete
Questions?

More Great New Products to come from TA Instruments