Waters™ | TA™ Instruments

THE WORLD'S FINEST LINE OF THERMOGRAVIMETRIC ANALYZERS

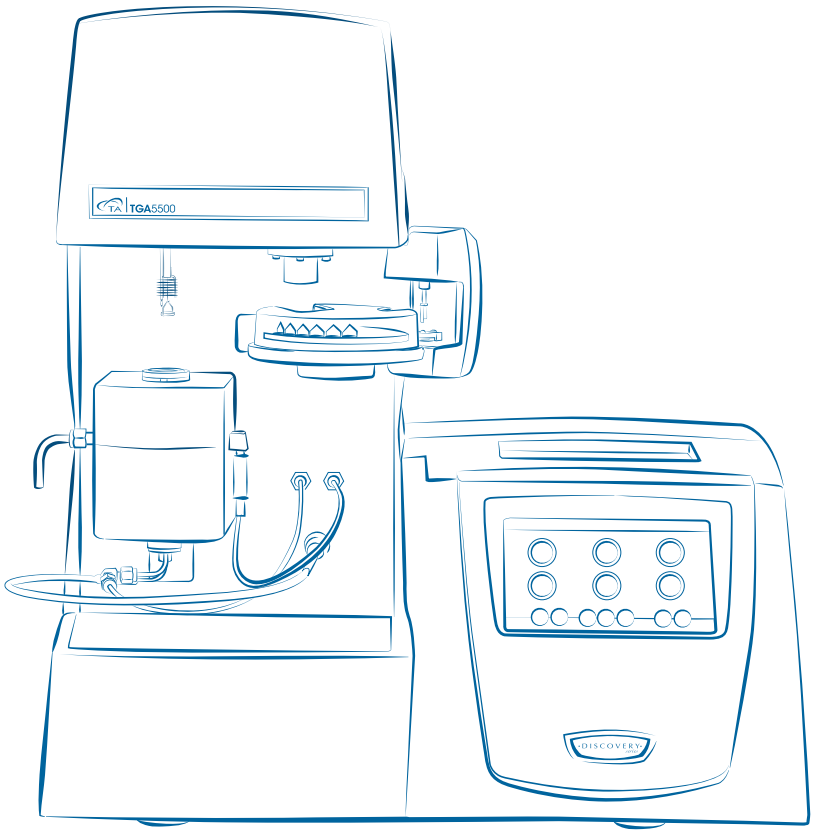
HIGH PERFORMANCE TGA SYSTEMS

that **deliver** the

Most Accuracy

Highest Sensitivity

Greatest Reliability



DISCOVERY TGA | THERMOGRAVIMETRIC ANALYSIS

TA Instruments™ invites you to experience the world's finest line of Thermogravimetric Analyzers, the Discovery™ TGA 55, TGA 550, and TGA 5500. Discover the advanced engineering and attention to detail that provides enhancements in every aspect of TGA technology and a new level of user experience. From the most cost-effective and flexible TGA with industry-leading performance, to the most advanced TGA available, there is a Discovery TGA to meet your needs and exceed your expectations.

TGA 55

Premium Performing TGA

The TGA 55 is specifically designed for those who want a rugged, reliable, and cost-effective TGA, and are not willing to compromise on performance. Utilizing TA's proprietary Tru-Mass™ Balance as the core of the measurement, the TGA 55 will outperform competitive research-grade models. Its sensitivity, accuracy, and ease-of-use make this TGA an ideal instrument for basic research in academic or industrial labs that need quality results.

TGA 550

Premium performance with advanced options and configuration flexibility

The TGA 550 will not only outperform competitive top-tier systems, but will also give users the flexibility to add advanced features like Hi-Res™ TGA, MTGA™, DTA signal, and our new 25-position autosampler. The performance, flexibility, and ease-of-use make this an excellent TGA for research and multi-user laboratories where a wide variety of TGA experiments are conducted and future expansion of analytical work is anticipated.

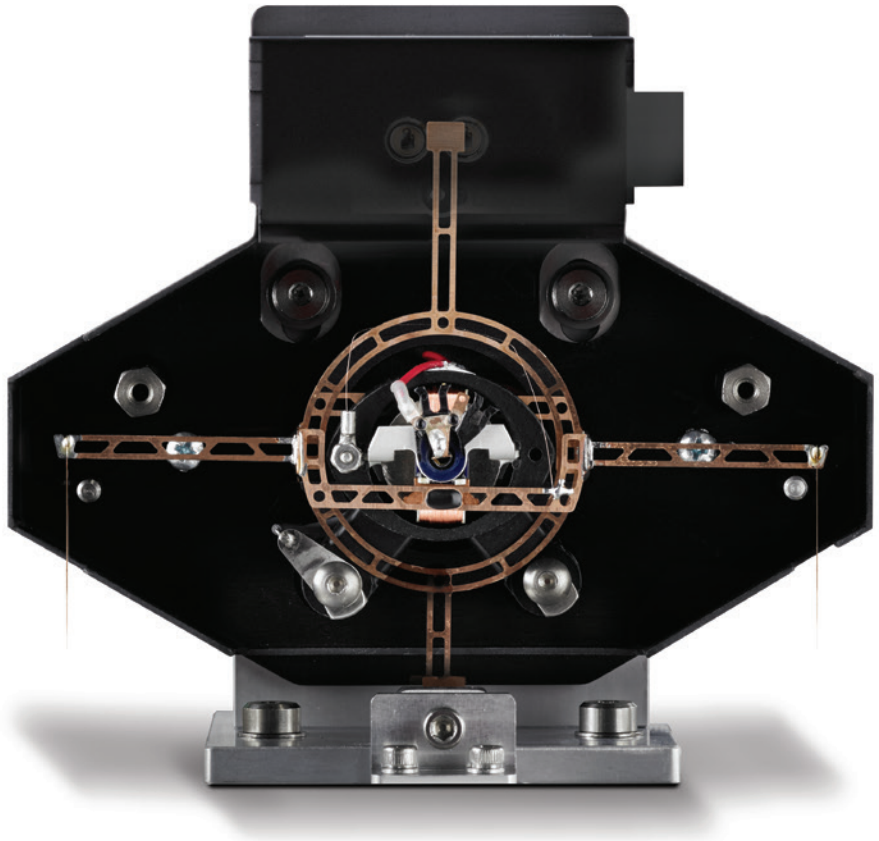
TGA 5500

Ultimate performance with every option to meet the requirements of the most demanding applications

The TGA 5500 is designed for the researcher who requires the highest level of performance and features in one package. Built to maximize temperature control and minimize signal drift, the TGA 5500 has less drift than any competitive TGA – even those using post-test data manipulation! The TA patented IR furnace* delivers the fastest heating and cooling rates available. The all-new 25-position autosampler takes productivity to the highest level, while also featuring the pan punch mechanism for automated sequencing of materials where the sample environment must be controlled prior to testing.

* U.S. Patent no. 7,416,328 and 7,566,167

NO ONE MAKES a **MORE SENSITIVE** and **ACCURATE THERMOBALANCE**



At the core of every new Discovery TGA is the proprietary Tru-Mass™ Balance. The Tru-Mass Balance system is Thermally isolated for high sensitivity in every laboratory environment, delivers the highest Resolution to separate components of the most challenging TGA samples, and has Ultra-low drift (Tru-Mass) for weight accuracy. Unlike competitive designs, the Discovery TGA delivers optimum performance without requiring baseline subtractions and other post-test manipulation required by competitors. The result is an innovative TGA with unrivaled performance in weight drift and sensitivity.

Balance Features and Benefits:

- Ultra-low drift balance design ensures accurate detection of even the smallest weight changes
- High capacity (1 g) Tru-Mass balance with auto-ranging capability to ensure the best sensitivity no matter the size of the sample
- Free-hanging sample eliminates the heat sink prevalent in top-loading designs, for the most efficient heat transfer and gas flow around the sample
- Thermally isolated balance with low drift and high sensitivity to deliver the most accurate real-time data

The proprietary Tru-Mass™ balance delivers pure real-time weight data.

Low **DRIFT**

High **CAPACITY**

Most **ACCURATE DATA**

WIDEST RANGE of HEATING & COOLING RATES

EVERY furnace on EVERY system is designed and manufactured by TA specifically for high performance TGA measurements. From the economical high-performing wire wound and EGA furnaces to the patented IR furnace* with industry-leading heating rates, there is a TGA furnace to meet your needs.

IR Furnace

The TGA 5500 is the only system offering patented infrared heating technology.

- Ambient to 1200 °C
- Linear controlled heating rates of 0.1 to 500 °C/min
- Ballistic heating rates >1600 °C/min for the highest efficiency available
- Fastest cooling for improved sample throughput
- Low volume, vacuum tight, and quartz lined with heated outlet option for best evolved gas results
- Quartz liner makes furnace easy to clean
- Integrated electromagnet for automated verification and calibration using Curie point standards

* U.S. Patent no. 7,416,328 and 7,566,167

Wire Wound (Pt/Rh) Furnace

Standard furnace for the TGA 55 and TGA 550.

- Ambient to 1000 °C
- Linear controlled heating rates of 0.1 to 100 °C/min
- Ballistic heating rates >600 °C/min
- Low mass furnace allows fast cooling for quick and efficient turnaround between runs

EGA Furnace

Optional Evolved Gas Analysis (EGA) furnace for the TGA 55 and TGA 550.

- Ambient to 1000 °C
- Linear controlled heating rates of 0.1 to 50˚C/min
- Low volume, vacuum tight, and quartz lined for excellent evolved gas results
- Quartz liner makes furnace easy to clean

All TA™ furnaces are built to be rugged and reliable and are covered by the industry's

ONLY 5-YEAR WARRANTY

BEST SAMPLE-ATMOSPHERE INTERACTION

All Discovery TGA models are designed with superior atmosphere control to meet the most demanding applications. Whether maintaining an inert atmosphere, switching to an oxidative purge, or maintaining a high vacuum, the Discovery TGA is up to the task.

Atmosphere Control Features and Benefits:

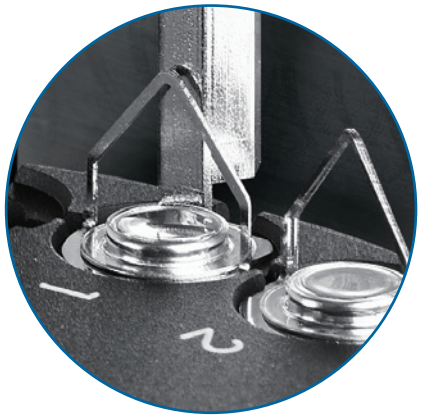
- Innovative Gas-Delivery Manifold (GDM) design eliminates potential leak points from tubing and hardware connections ensuring the most consistent, repeatable atmosphere
- Integrated software-controlled gas switching for experiments requiring dynamic or reactive atmospheres
- An optional Blending Gas Delivery Module features in-line mixing of binary gases and advanced atmosphere control where the concentration ratio of the gases may be held constant, incremented, or ramped
- Horizontal gas purge for optimal sample-atmosphere interaction
- Vacuum tight to ensure inert, oxygen-free atmospheres
- Sealed pan option to maintain the atmosphere of the sample until the experiment starts

FLEXIBLE DESIGN for ENHANCED PRODUCTIVITY

The Discovery TGA features a 25-position autosampler designed to be the most rugged and reliable system ever developed.

Autosampler Features and Benefits:

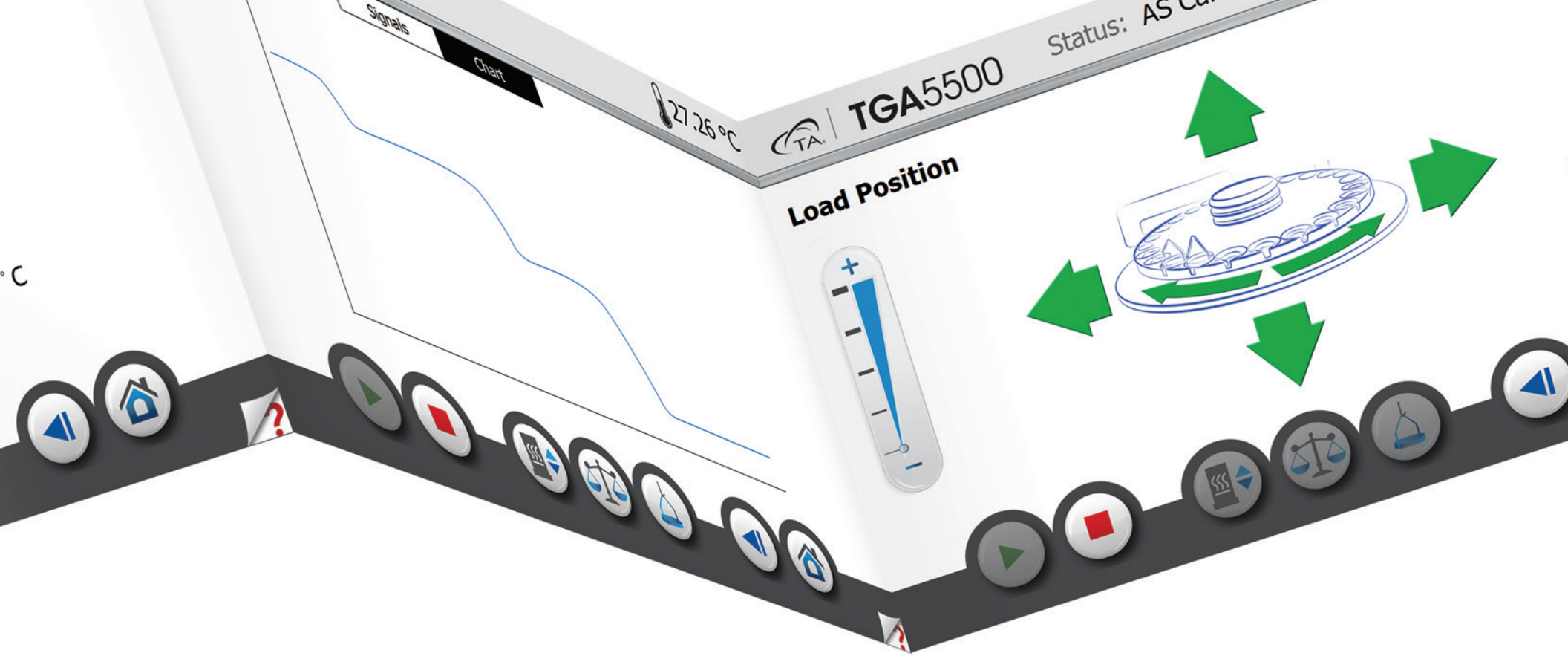
- Compatible with all pan types and sizes for ultimate flexibility
- Sealed pan* and pan punch option for effective isolation of air-sensitive or volatile samples
- Scheduling of unattended calibrations and verifications give scientists more time for research
- New TRIOS software makes it easier than ever to manage and run a large and diverse sample queue. The Design view and Running queue allow for quick and efficient autosampler programming



[1] TGA 5500 only

* U.S. Patent no. 6,840,668

TECHNOLOGY | "APP" STYLE TOUCH SCREEN



One Touch Away™

Touch Screen Features and Benefits:

- Ergonomic design for easy viewing and operation
- Packed with functionality to simplify operation and enhance user experience. The touch screen includes:
  - Start/stop runs
  - Real-time signals
  - Active method viewing
  - Autosampler calibration
  - System information
  - Test and instrument status
  - Real-time plot
  - Advance method segments
  - Loading/unloading and taring pans

The app-style touch screen, powerful new TRIOS software and the robust, reliable autosampler with automated calibration and verification routines all work seamlessly to dramatically improve laboratory workflow and productivity.

ITS NEVER BEEN EASIER TO GET GREAT DATA!

TECHNOLOGY | TRIOS SOFTWARE

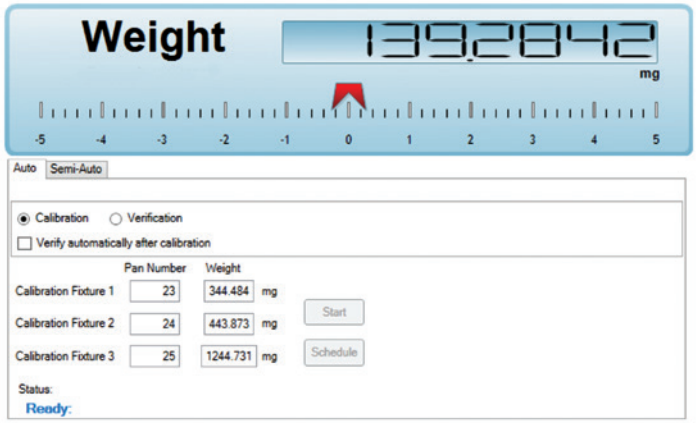
Discover powerful TRIOS™ software that delivers exceptional user experience in a combined package for instrument control, data analysis, and reporting for thermal analysis and rheology. New features such as multiple calibration sets, real-time test method editing, and inter-laboratory data and test method sharing provide unmatched flexibility, while one-click analysis and custom reporting raise productivity to new levels.

TRIOS Features:

- Control multiple instruments with a single PC and software package
- Overlay and compare results across techniques including DSC, TGA, DMA, SDT and rheometers
- One-click repeated analysis for increased productivity
- Automated custom report generation including: experimental details, data plots and tables, and analysis results
- Convenient data export to plain-text, CSV, XML, Excel®, Word®, PowerPoint®, and image formats
- Optional TRIOS Guardian™ with electronic signatures for audit trail and data integrity

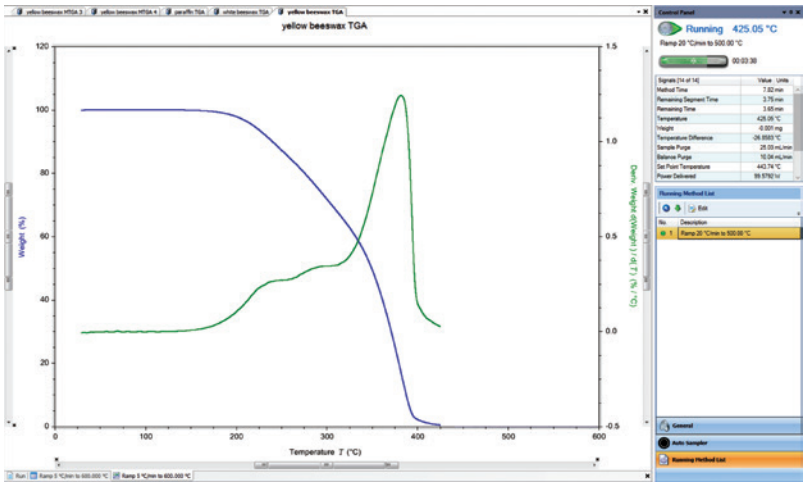
Ease of Use

TRIOS software makes calibration and operation of the entire line of Thermogravimetric Analyzers simple. Users can easily generate multiple calibration data sets under varying experimental conditions (e.g. different heating rates or gas selections) and seamlessly switch between them to match the experimental conditions used for sample testing. Real-time signals and the progress of running experiments is readily available, with the added capability of modifying a running method on the fly. TRIOS software offers a level of flexibility that is unmatched in the industry.



Complete Data Record

The advanced data collection system automatically saves all relevant signals, active calibrations, and system settings. This comprehensive set of information is invaluable for method development, procedure deployment and data validation.



The Most **VERSATILE CONTROL** and **ANALYSIS SOFTWARE**

Complete Data Analysis Capabilities

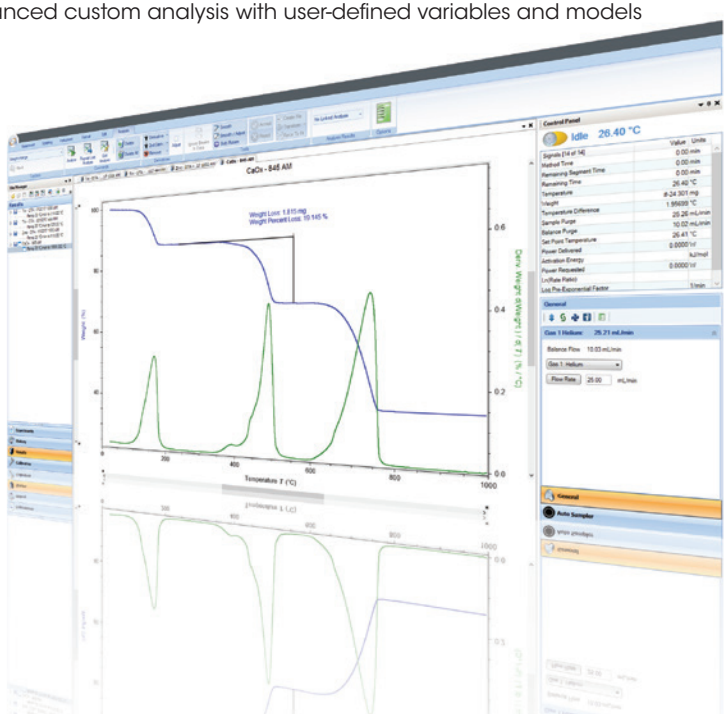
A comprehensive set of relevant tools are available for real-time data analysis, even during experiments. Gain actionable insights into your material's behavior through a powerful and versatile set of features seamlessly integrated into TRIOS.

All Standard TGA Analyses:

- Weight change (absolute and as a percentage)
- Residue content
- 1st and 2nd derivatives
- Weight at a specified time or temperature
- Weight loss at a specified time or temperature
- Peak height and area
- Temperature at peak maximum
- Onset and endset analyses
- Step transition analysis
- Easily import and export TGA data with TRIOS

Advanced Analysis Capabilities:

- Activation energy determination with Modulated TGA™
- Decomposition kinetics as obtained from constant or dynamic heating rate, and constant reaction rate experiments
- DTA signal for endothermic and exothermic thermal events such as melting, crystallization, cure reactions and decomposition
- Advanced custom analysis with user-defined variables and models



TRIOS JSON Export Feature

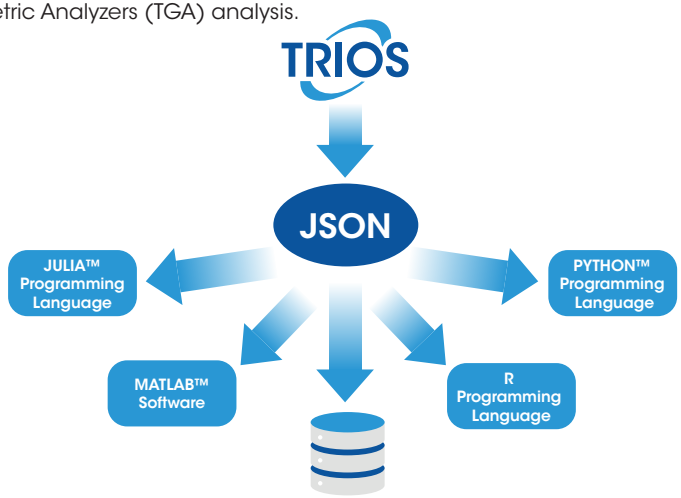
Powerful human- and machine-readable data in an open standard

Unlock the power of your Thermogravimetric Analyzers (TGA) data with the TA Instruments™ TRIOS JSON Export Feature, designed to revolutionize data management and utilization. This powerful new capability seamlessly integrates TRIOS Software data with data science tools, automation workflows, and lab systems such as LIMS, making data handling more efficient and accessible than ever before.

Key Features:

- **Seamless Integration:** Convert your TRIOS data into the open standard JSON format, JSON is available:
  - Automatically on every save (enabled in options)
  - Through manual export dialogs
  - As part of the "Send to LIMS" functionality
  - Via the "Batch" processing dialog or from the command line
  - In TRIOS AutoPilot
- **Data Consistency:** Our publicly available JSON schema helps ensure a consistent data structure, allowing you to write code once and apply it almost universally across most of your data files.
- **Python Library:** Open-sourced Python Library, TA™ Data Kit (available at github.com/TA-Instruments/tadatakit), to simplify your data ingestion or learn how to take advantage of the power of our data with our code examples.

With the TRIOS JSON Export Feature, you're not just collecting data – you're unlocking its full potential. Experience streamlined workflows, reliable results, and a community-driven approach to Thermogravimetric Analyzers (TGA) analysis.



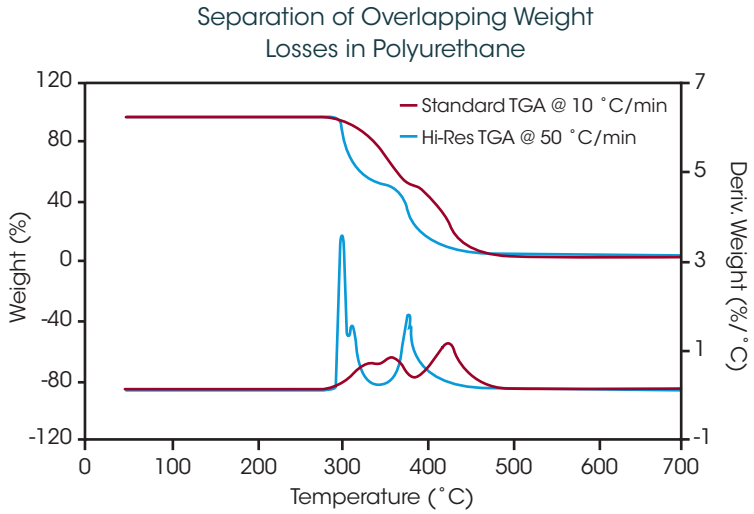
In Hi-Res™ TGA, the heating rate is controlled by the decomposition rate of the sample. The Discovery TGA 5500 and 550 designs are ideal for these measurements, featuring rapid response furnaces for precise temperature control and sensitive thermobalances designed to quickly detect small weight changes.

Benefits of Hi-Res TGA include:

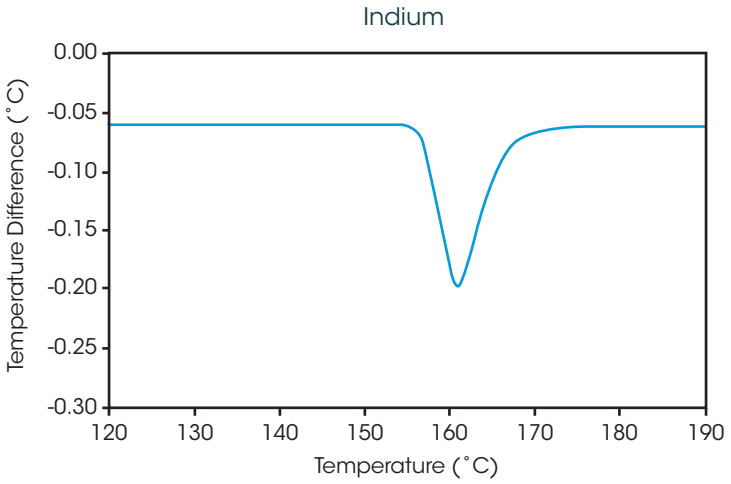
- Separation of broad and overlapping weight losses
- Increased productivity with better resolution
- Rapid survey over wide temperature range with excellent resolution
- Simple method setup

DTA Signal

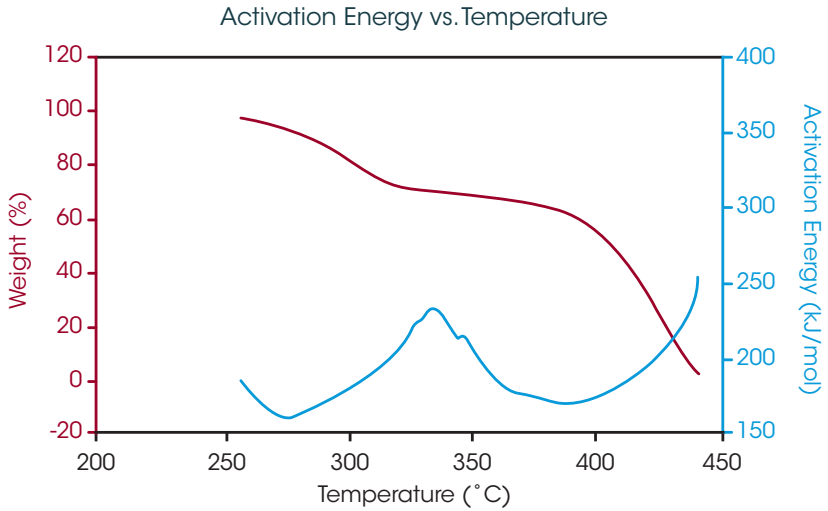
The DTA signal is a qualitative measurement of endothermic and exothermic reactions occurring in the TGA. This signal can also be used for temperature calibration by using melting point standards.



The figure above shows the Hi-Res TGA results for a polyurethane material by standard and Hi-Res TGA. The superior resolution provided by the Hi-Res technique is clearly evident in both the TGA weight loss and the first derivative (DTG) signals. The latter signal is especially useful in defining the onset and the endset of the individual weight loss segments, as well as indicating subtle events that provide a "fingerprint" of the sample.



DISCOVER more about your MATERIALS



TA's patented MTGA™ * is another TA Instruments innovation that offers advantages for material decomposition studies. Developed from the proprietary heater control technology utilized by Hi-Res™ TGA and MDSC®, MTGA produces model-free kinetic data. Activation energy can be continuously calculated during the test and studied as a function of time, temperature, and conversion.

Benefits of MTGA include:

- Increased productivity for studying kinetics
- Model-free kinetic data
- Can be combined with Hi-Res TGA for better separation of overlapping weight losses
- Direct determination of activation energy

The figure to the left shows the MTGA plot from a kinetic study of the effect of temperature on the decomposition of 60 % ethylene vinyl acetate (EVA) in a single analysis. The plot quantitatively shows the EVA decomposition profile and changes in activation energy as functions of temperature. The data supports a dual-step decomposition mechanism. MTGA can also monitor activation energy as a function of conversion, which can infer the mechanism involved.

* U.S. Patent no. 6,113,261 and 6,336,741

TECHNOLOGY | EVOLVED GAS ANALYSIS

Evolved gas analysis involves the qualitative investigation of the evolved gas products from a TGA experiment. These products are generally the result of decomposition, but can also evolve from desorption, evaporation or chemical reactions. Evolved gas analysis is typically performed by interfacing a mass spectrometer (MS), Fourier transform infrared spectrometer (FTIR), or gas chromatograph (GC) to the exit port of the TGA furnace. Through the use of a heated transfer line, the evolved gas stream is delivered to the MS, FTIR, or GC instrument, and the compositional analysis is performed in real time. TA Instruments offers a 300 amu benchtop, quadrupole mass spectrometer with a heated capillary interface, and TGA module-specific interface kits for the Discovery TGA. TA offers alternatively an actively flow and pressure controlled interface module for gas sampling to a variety of FTIR and/or GC instruments.

The Discovery TGA is the ideal platform for evolved gas analysis studies. A horizontal purge stream over the sample and a short path to the exit port eliminates dead volume in the furnace, thereby reducing product dilution and optimizing EGA sensitivity. Heated EGA adapters are designed to interface directly with the MS, FTIR, or GC transfer line to ensure continuous heating of the offgas stream through the furnace wall, dramatically reducing offgas condensation and improving EGA sensitivity.

TA Instruments' TRIOS software supports the importation of MS (trend analysis) and FTIR data (Gram-Schmidt and Chemigram reconstructions), allowing TGA and EGA data to be displayed on a common axis of temperature and/or time.

EGA Features and Benefits:

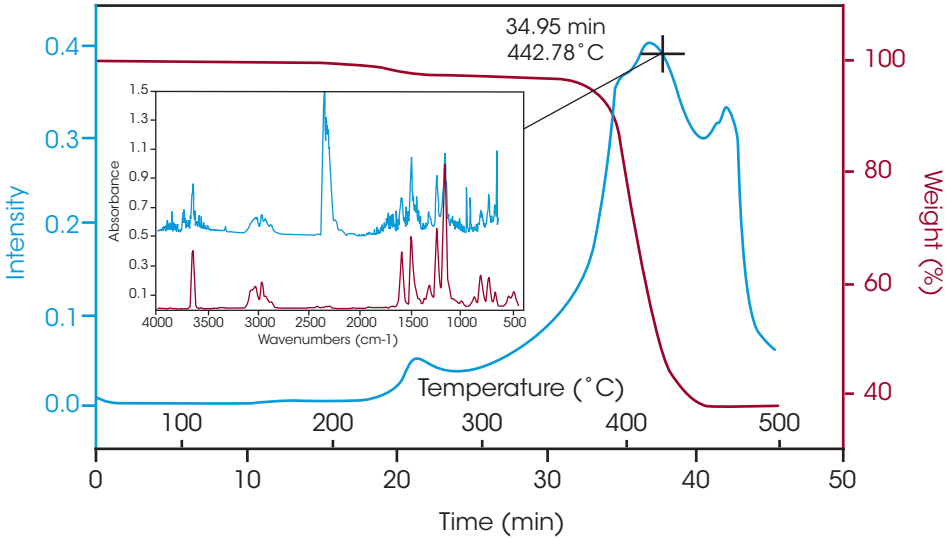
- Identification of decomposition products
- Additional information for the interpretation of the reactions during TGA scans
- Exact control of the furnace atmosphere before and during experiments

Design Features and Benefits of the Discovery TGA for EGA Analysis:

- Horizontal purge stream over the sample for optimal sensitivity
- Low volume furnace reduces dilution by eliminating dead volume
- Heated EGA adaptor eliminates cold spots and condensation
- Powerful TRIOS software allows importation of MS, FTIR, or GC data for improved data interpretation

TGA-FTIR: Phenolic Resin Decomposition

This figure contains the TGA-FTIR results for the thermal decomposition of a phenolic resin adhesive. A Gram-Schmidt reconstruction of the time-resolved FTIR spectra is compared to the weight loss signal as a function of time and temperature. The inset image contains the FTIR spectrum of the offgas composition at 34.95 minutes, near the point of the maximum rate of decomposition. The FTIR spectrum corresponding to this temperature indicates that the offgas products are primarily composed of phenols, including bisphenol A, which is included as a comparison spectrum. This level of chemical specificity is useful in comparing similar products, quality control, and fingerprint analysis.

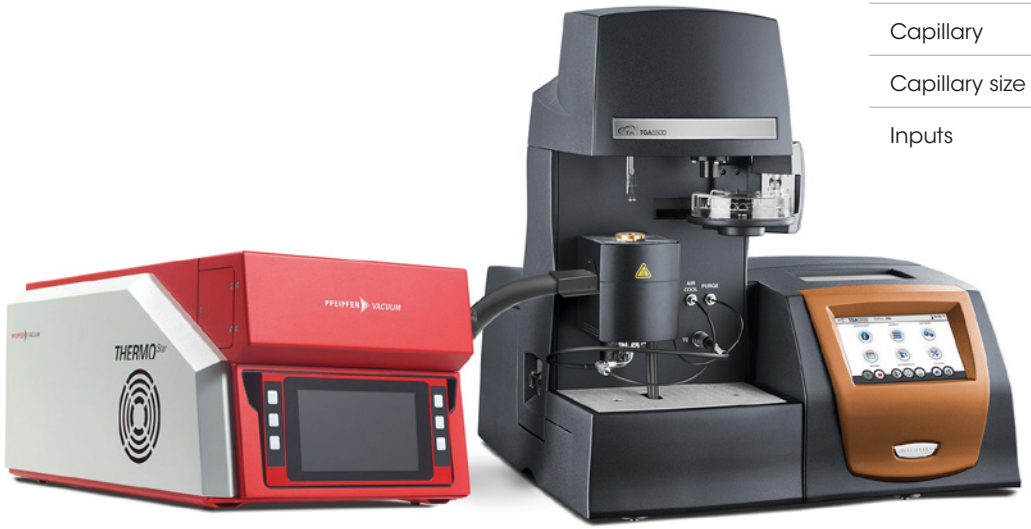


TECHNOLOGY | THE PFEIFFER MS

The Pfeiffer MS is a benchtop quadrupole mass spectrometer, designed and optimized for evolved gas analysis. It features industry-standard technology configured for the efficient transfer and rapid detection of offgas from the TGA furnace. Parts per billion (ppb) sensitivity is ensured with the state-of-the-art quadrupole detection system, including a closed ion source, a single mass filter, and a dual (Faraday and Secondary Electron Multiplier) detector system. This analyzer configuration is selected to optimize sensitivity and long-term stability performance.

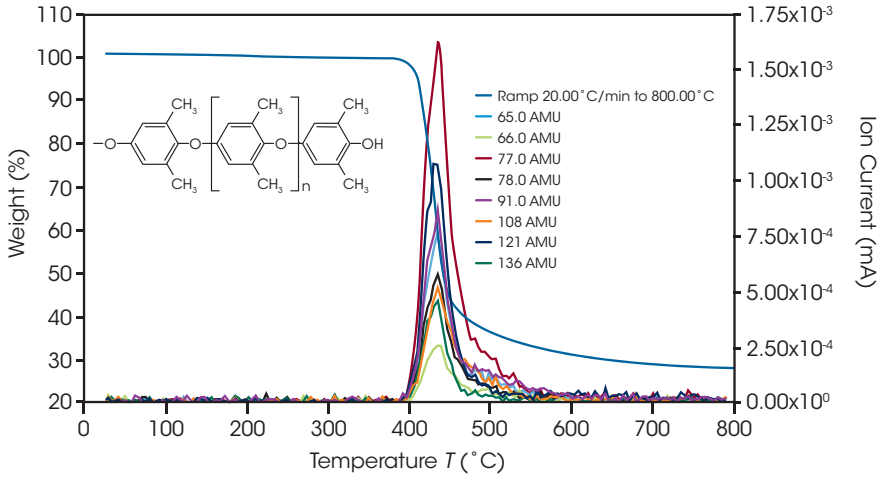
Control of the experimental parameters and analysis of the mass spectral data is achieved through a user-friendly, recipe-driven software interface. Data collection can be triggered directly from the TGA software, and the resulting MS data can be combined with the corresponding TGA results for direct overlaying and comparison.

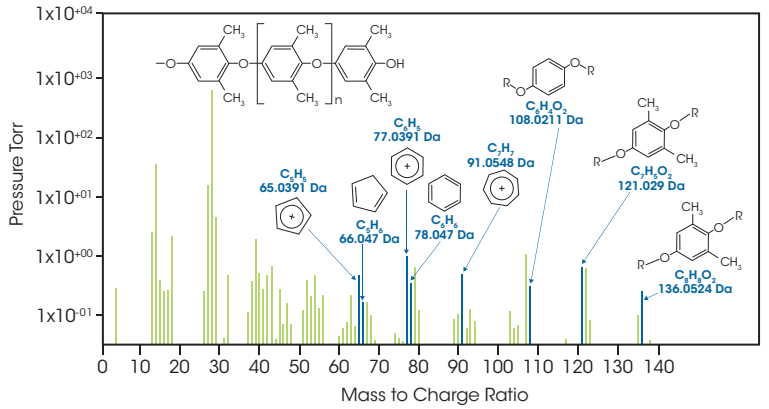
Parameter	Performance
Mass range	1-300 amu
Mass Resolution	>0.5 amu
Sensitivity	< 100 ppb (gas-dependent)
Ionization Source	Electron Ionization
Detector System	Dual (Faraday and Second Electron Multiplier)
Sample Pressure	1 atm (nominal)
Bar Graph and Multiple Ion Detection	Bar graph and Peak Jump
Scanning Speed	
Bar graph Mode	>500 amu/s
Multiple Ion Detection	>500 channels/s
Transfer Line Temperature	200°C
Transfer Line	2.0 meters, flexible
Filaments	Dual, customer changeable
Capillary	Quartz, changeable
Capillary size	I.D. = 0.15 mm
Inputs	Data collection controlled by TGA Trigger



Decomposition of an Engineered Plastic

Poly(phenylene oxide), or PPO, is a high-performance, engineered thermoplastic with desirable specifications for heat resistance and dimensional stability. With a glass transition temperature as high as 215°C, the processing temperature of PPO would need to be high and will result in a cumbersome and costly manufacturing process. In many cases, other polymers such as polystyrene (HIPS) are blended with PPO to both aid in processing and improve the ductility over PPO alone. In this example, neat PPO is heated through decomposition in an inert nitrogen atmosphere with the offgas collected by the attached MS. The TGA-MS hyphenated technique allows for the detection and identification of the resultant decomposition products. The data is displayed as an overlay of ion current and weight loss with respect to temperature. TGA shows a monotonic weight loss step; however, the mass spectroscopy data presents the detection of several decomposition entities that range in mass to charge ratios of 65 to 136 amu, which is the molecular ion of the repeating unit. Proposed possible decomposition products, based on the structure of the polyether, are also shown.

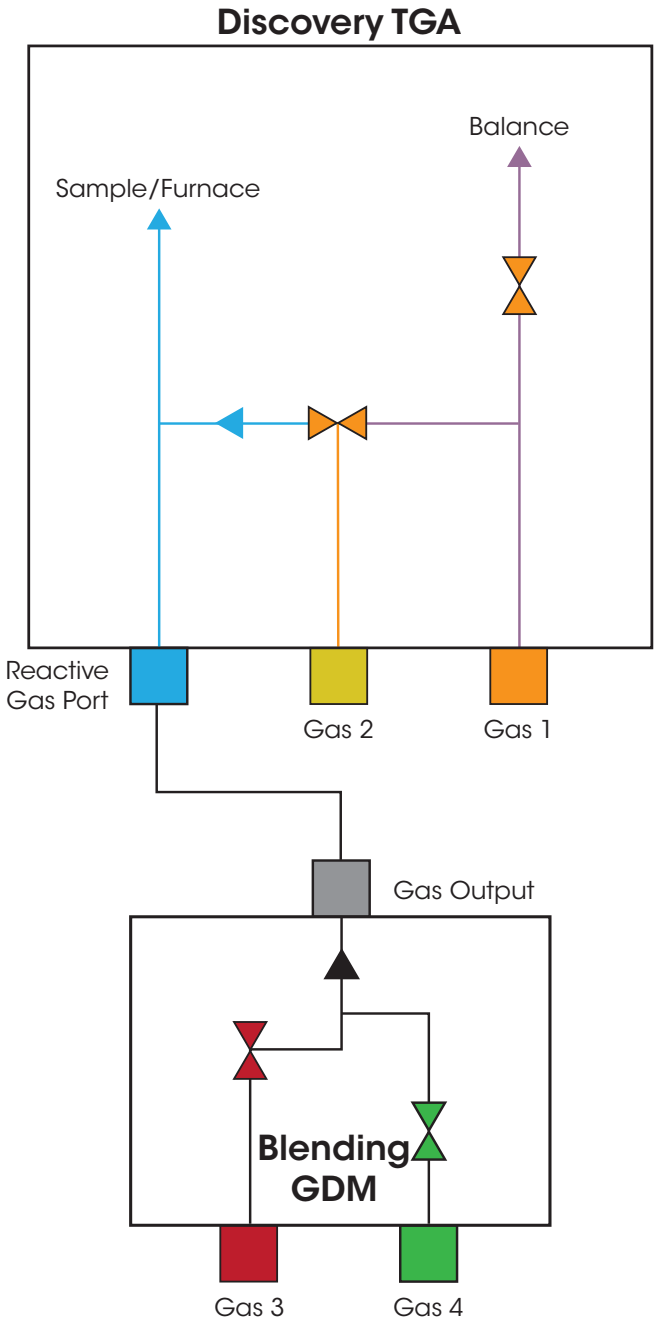




TECHNOLOGY | BLENDING GAS DELIVERY MODULE

Blending Gas Delivery Module

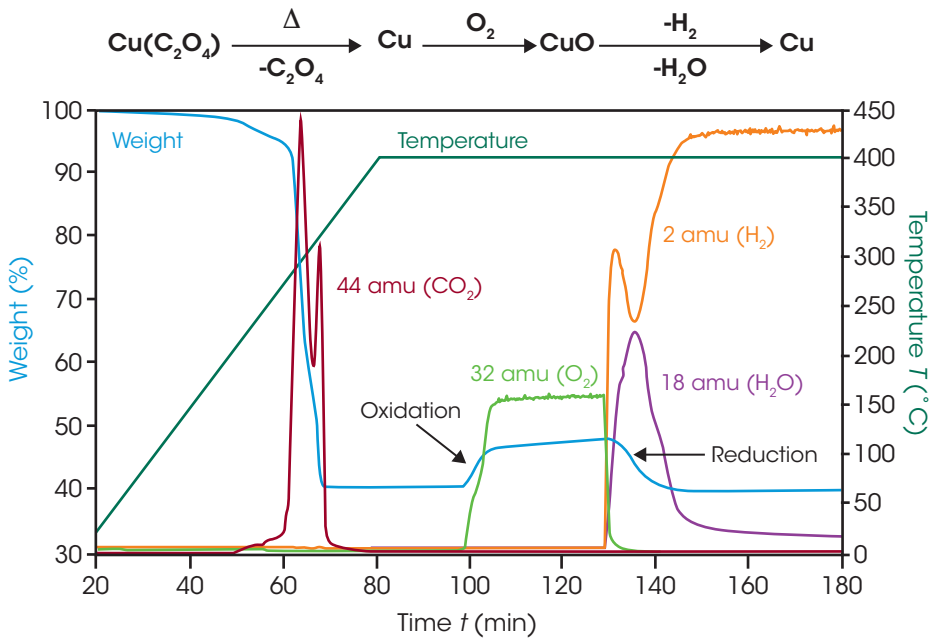
The Blending Gas Delivery Module (Blending GDM) delivers flexibility in gas handling on the Discovery TGA 5500 and TGA 550. The Blending GDM is an external accessory with two gas inlet ports that, when connected to the reactive gas port on the TGA gives the user a total of four gases to control. The software-controlled accessory allows for automated switching between the four gas ports as well as blending of binary mixtures of gases. The added blending capability allows for TGA experiments to be carried out in an atmosphere where the concentration ratio between gases may be fixed, stepped incrementally or ramped at a controlled rate. The Blending GDM is compatible with Nitrogen, Argon, Helium, Air, Oxygen, Carbon Dioxide, and Forming Gas and can be used to study sorption of gases onto a material, redox reactions, and thermal stability of materials in a controlled atmosphere.



Gas Port	Gases Supported	Blend Options
1 Instrument, also used as balance purge	N_2, He, Ar	3 or 4
2 Instrument	N_2, O_2, Air, He, Ar	3 or 4
3 Blending GDM	N_2, O_2, Air, He, Ar, Forming Gas, CO, CO_2	1, 2 or 4
4 Blending GDM	N_2, O_2, Air, He, Ar, Forming Gas, CO, CO_2	1, 2 or 3

Redox Reaction of Copper Oxalate

Copper oxalate (CuC_2O_4) is a salt that decomposes to elemental copper upon heating in an inert atmosphere. It is often used to measure the inertness of the TGA atmosphere, as the high surface area of copper is readily oxidized at high temperatures. In this example an oxidation-reduction (redox) reaction experiment was accomplished using the Blending GDM, Pfeiffer MS and the Discovery TGA. After decomposition of the oxalate during the initial temperature ramp, oxygen was introduced into the TGA sample chamber resulting in the formation of copper (II) oxide. Subsequent reduction of the copper oxide was achieved through the introduction of small amounts of hydrogen gas. Forming gas was safely used as the hydrogen source in the TGA.



TECHNOLOGY | TGA OF ATMOSPHERE SENSITIVE MATERIALS

Atmosphere-sensitive samples require handling and analysis without air contact

Advanced materials are often reactive with moisture or oxygen in the air. Contact to air can then lead to undesirable material changes or violent reactions.

For TGA measurements with atmosphere-sensitive samples, traditionally sealed pans are used. The sample can be prepared under protective atmosphere and sealed in the pan with a lid. The lid is pierced open shortly before the sample pan is loaded into the TGA, thus minimizing the time the sample is exposed to air. Discovery TGA can operate sealed pans through the pan punch option (please refer to page 11).

For new high-performance materials such as battery materials, pharmaceuticals, catalysts, and high-performance polymers, even the brief contact with air between opening the pan and loading it into the TGA furnace can compromise data quality or pose a risk to the user.

TA Instruments offers two different solutions for the completely inert handling and analysis. The solutions on the next pages offer the optimal solution for every application with highly atmosphere-sensitive samples.

Adaptor kit for seamless glovebox installation of Discovery TGA

An adaptor kit enables seamless installation of Discovery TGA series instruments in the inert environment of a glovebox. It has never been so simple to perform thermogravimetric analysis of atmosphere-sensitive materials in inert protective environments. Robust design and state-of-the-art technology ensure the TGA performance is not impacted, delivering the same accuracy and precision as when operated outside a glovebox.

Discovery TGA instruments can be operated in N_2 or Ar purged gloveboxes covering all industries' needs.

Features and Benefits:

- **Glovebox operation** of TA Instruments Discovery TGA provides reliable material data of atmosphere sensitive samples.
- **No instrument modifications required** to install Discovery TGA in a glovebox maintains accuracy of analysis data.
- **N_2-sensitive battery materials** can be analyzed without contamination in argon (Ar) purged gloveboxes.
- **Plug-and-play installation compatible with most glovebox brands and types** through effectively designed installation kits employing standardized ISO-KF40 connections.

TGA Smart-Seal™ Pans

The innovative TGA Smart-Seal Pan from TA Instruments is an effective and user-friendly solution for analyzing highly atmosphere-sensitive sample materials in a standard thermogravimetric analyzer without installing the TGA instrument in a glovebox.

The hermetically sealed pans help ensure inert sample handling by maintaining a controlled environment throughout the sample loading into a Discovery TGA instrument. The TGA Smart-Seal Pan opens automatically inside the closed TGA furnace once the temperature reaches 55°C.

TGA Smart-Seal Pans offer uncompromising TGA data quality while simplifying operation and reducing costs compared to installing the TGA in a glovebox.

Features and Benefits:

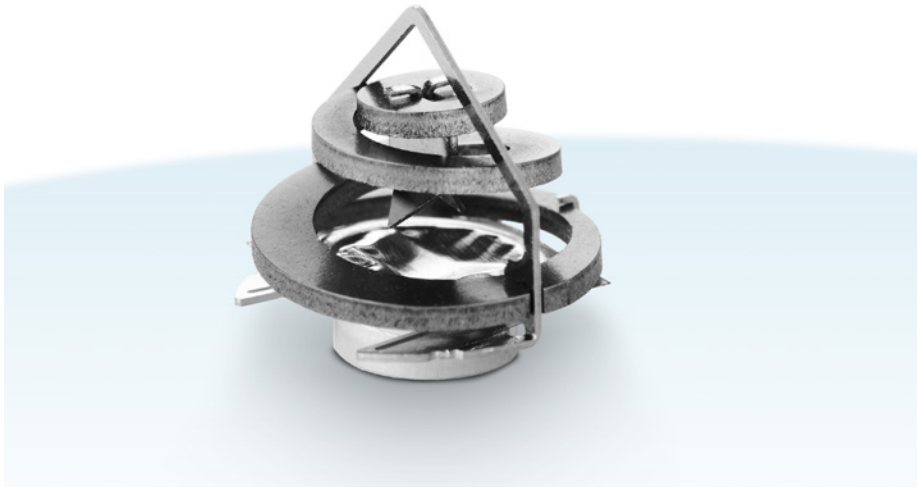
- **Enhanced sample protection** through the hermetic pan seal.
- **Automatic temperature-activated pan opening** inside the closed TGA furnace.
- **Ease of use** with straightforward sample encapsulation and handling comparable to standard TGA test.
- **Cost efficient** through significant cost and space savings compared to glovebox installation of TGA.
- **Evolved Gas Analysis – EGA** by using standard hyphenation without the complex gas sampling setups often used for glovebox installed TGAs, enabling easy analysis of decomposition gases.

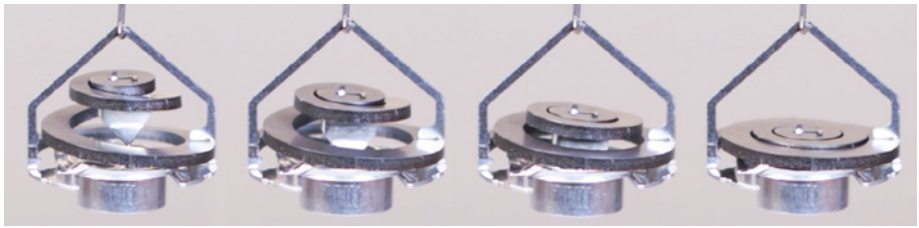
Proprietary Shape-Memory Alloy Technology

The TGA Smart-Seal Pan consists of a metal sample pan, a metal foil lid, and a bail assembly with temperature-activated cutter which can be used for TGA analysis with atmosphere sensitive samples.

The sample is filled into the sample pan under a protective atmosphere. Then the pan is sealed with a metal foil lid. This sealing helps ensure protection of the sample from the atmosphere during the subsequent transfer to the TGA installed under normal ambient conditions.

After the sealed TGA Smart-Seal Pan has been loaded from the autosampler to the TGA, the furnace is closed and can be purged. Then the heating program of the TGA begins. The innovation of the TGA Smart-Seal Pan is its autonomous, temperature-activated opening mechanism. In the bail assembly, a shape memory alloy activates the cutter around 55 °C, which opens the foil on the crucible. This opens the seal of the pan automatically without user interaction in the closed and purged TGA furnace and the TGA analysis can be carried out as usual.





ANALYSIS of ATMOSPHERE SENSITIVE materials

$LiPF_6$ thermal decomposition studied by TGA installed in a glovebox and using the TGA Smart-Seal™ Pans

Lithium hexafluorophosphate ($LiPF_6$) is highly hygroscopic and a commonly used electrolyte salt in lithium-ion batteries. Under dry conditions, it decomposes in a single step to lithium fluoride (LiF) and phosphorous pentafluoride (PF_5). Under wet conditions, it can produce both hydrogen fluoride (HF) and phosphoryl fluoride (POF_3) along the two separate decomposition paths shown below.

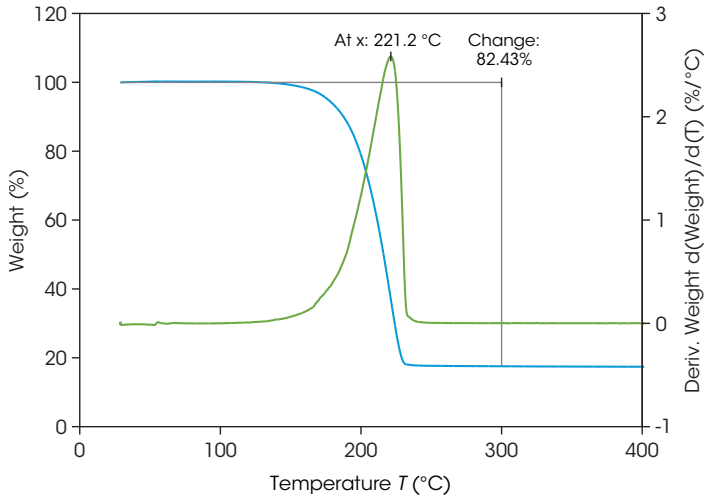
Dry $LiPF_6 \rightarrow LiF + PF_5$

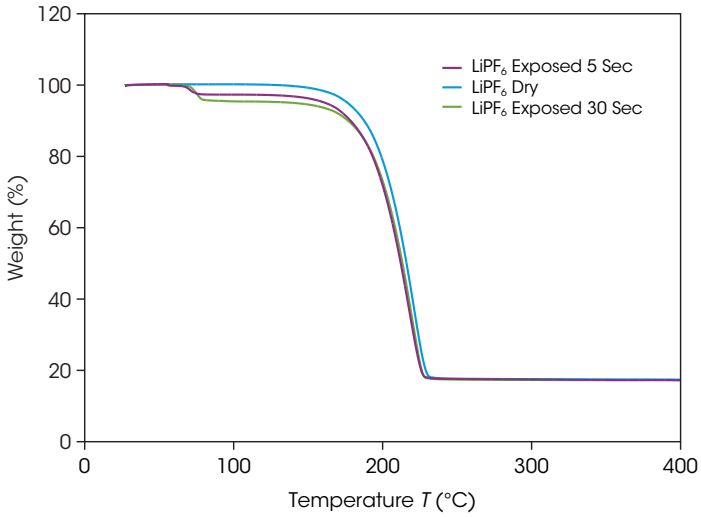
Wet $LiPF_6 + H_2O \rightarrow LiF + POF_3 + 2HF$

$PF_5 + H_2O \rightarrow POF_3 + 2HF$

The data in the left diagram shows the thermal decomposition of dry $LiPF_6$ measured with a Discovery TGA installed in a glovebox using the glovebox installation kit. The result is consistent with published data exhibiting decomposition in a single weight loss step of approximately 82.4%.

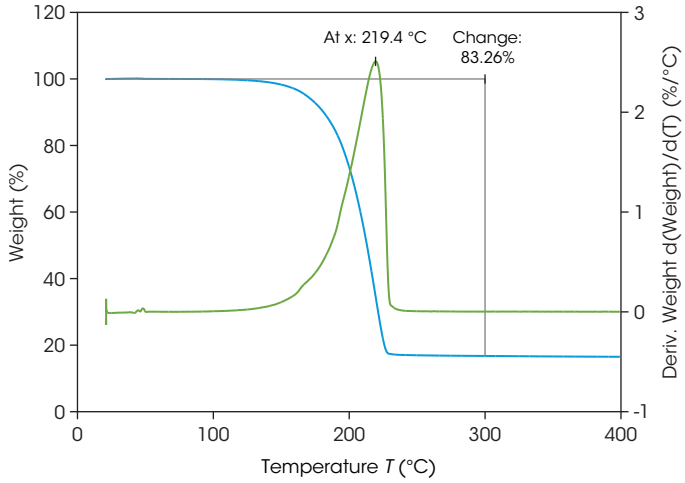
In the right diagram the thermal decomposition of dry $LiPF_6$ is compared with data of two experiments in which the material was exposed to ambient air for approximately 5 and 30 seconds prior to the TGA run. The short exposures to air lead to a second weight loss event. The additional weight losses for the 5 and 30 second exposures are 2.3% and 4.3%, respectively, thus demonstrating growth with increased exposure time.





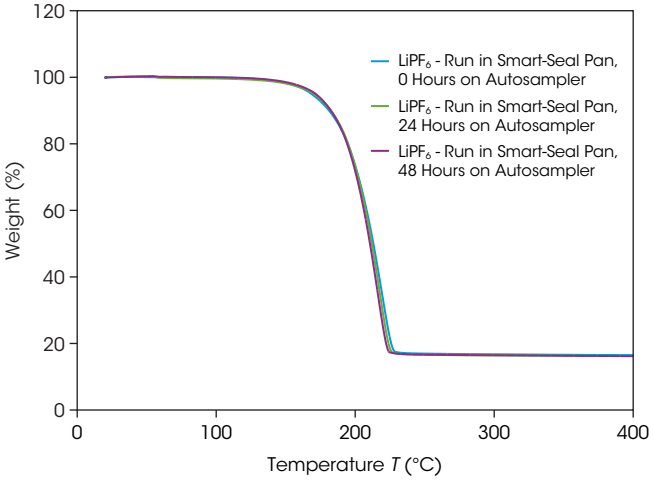
In the diagram to the right the thermal decomposition of $LiPF_6$ measured in a Discovery TGA installed under normal ambient conditions is shown. The sample was sealed in the TGA Smart-Seal Pan inside a glovebox and then transferred to the ambient TGA for analysis.

Again, the $LiPF_6$ decomposes in a single weight loss event of 83.3%. No second weight loss event indicating humidity contamination is detected. The small feature in the derivative at approximately 55°C is due to the opening of the TGA Smart-Seal Pan in the furnace.



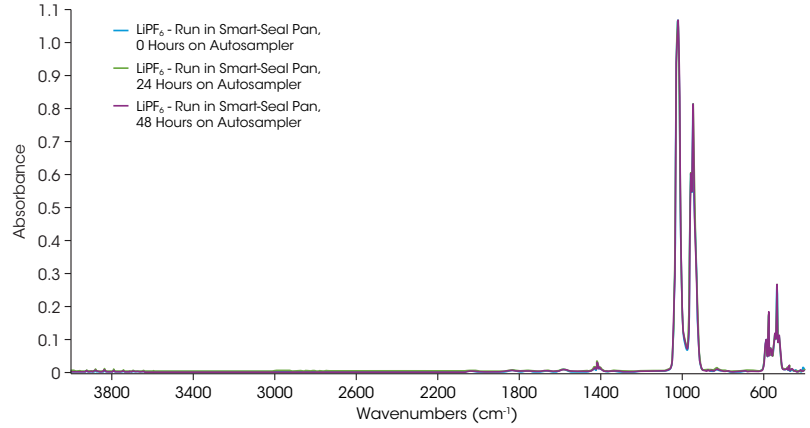
The diagram to the right compares $LiPF_6$ decomposition measured in an ambient TGA using Smart-Seal Pans. One sample was run immediately after sealing the pan, the other remained sealed on the autosampler tray for 24 and 48 hours. All samples were prepared identically in the glovebox before transfer to the TGA autosampler.

No indication of a second weight loss is detected for any sample. The data prove that the seal on the TGA Smart-Seal Pan is excellent and can protect the $LiPF_6$ material for at least 48 hours.



In-situ FTIR data on the evolved gasses of the $LiPF_6$ decomposition was collected. One distinct advantage of using TGA Smart-Seal Pans with an ambient TGA over glovebox installation is a much easier connection to external gas analyzers.

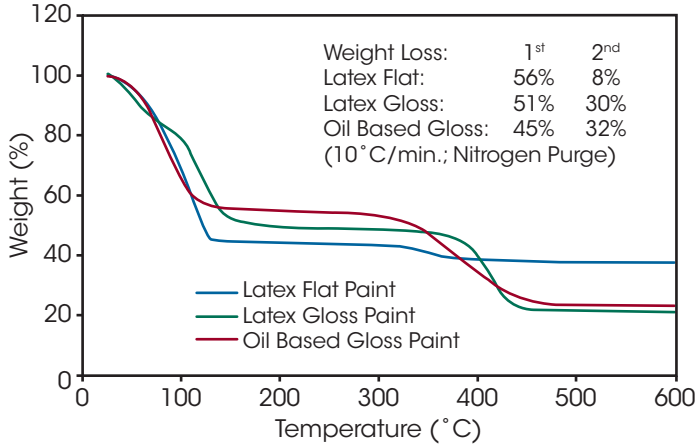
The diagram to the right overlays of the peak IR-spectra for the TGA data shown above for samples with different residence times on the autosampler. In all three cases, the spectrum is that of PF_5 which is expected when decomposing dry $LiPF_6$.



THERMOGRAVIMETRIC ANALYZERS | APPLICATIONS

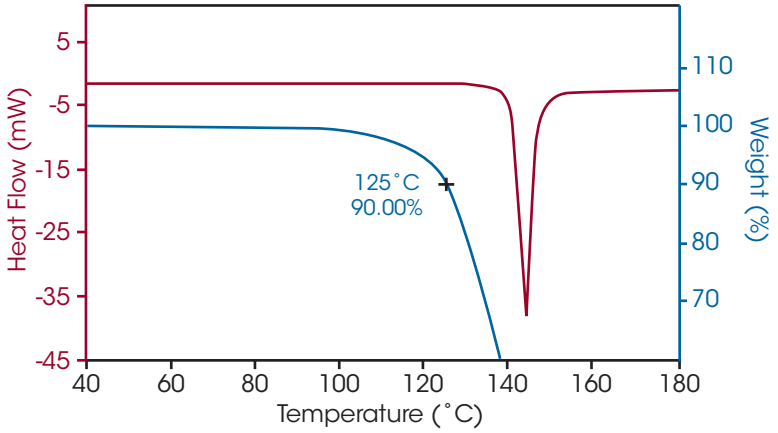
Compositional Analysis

TGA is used to determine sample composition by measuring the weight of each component as it volatilizes or decomposes under controlled conditions of temperature, time, and atmosphere. This figure shows quantitative differences in type, amount, and decomposition mechanism of the main polymers in three paint samples. A more detailed examination of the profiles below 150°C may reveal further information on the amount and possible nature of the carrier solvent (aqueous or oil) used in each paint.



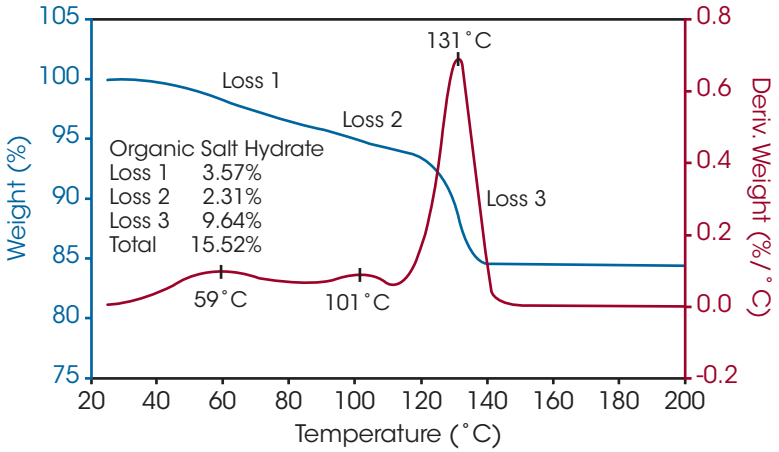
Verification of Thermal Events

TGA is very useful in conjunction with other thermal analysis techniques, such as DSC, and is often critical to understanding the true nature of thermal events. In this data, a pharmaceutical material undergoes an endothermic transition above 125°C, which was previously thought to be melting. TGA analysis demonstrates considerable weight loss below 125°C, which suggests that the endotherm is actually decomposition. DSC analysis at multiple rates exposes rate-dependence of this transition, which confirms decomposition.



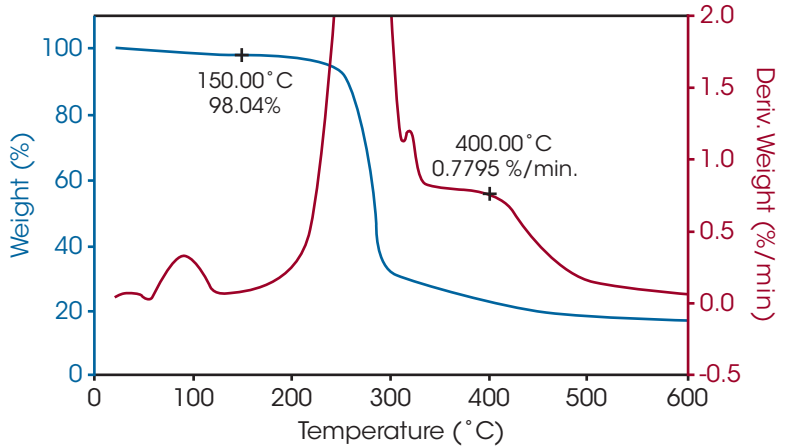
Volatiles Analysis

TGA determinations of absorbed, bound, or occluded moisture and organic volatiles, are important analyses for product performance and environmental acceptance. Analysis of an organic salt hydrate in nitrogen atmosphere shows a bound-water content of 9.6%, and two lower temperature weight losses of 3.6% and 2.3% respectively. These losses are likely due to adsorbed moisture at the salt surface, or held to it by weak attractive forces.



Moisture Content & Thermal Stability of a Pharmaceutical Material

TGA is a useful technique for determining the absolute and relative thermal stability of pharmaceutical compounds, as well as the moisture content. In this example, an active pharmaceutical ingredient (API) is analyzed by TGA at a heating rate of 10°C/min. The data show a small (~2%) weight loss below 150°C, which is typical for adsorbed water. The material is relatively stable up to 200°C, after which a large, multi-step weight loss is indicative of thermal decomposition.



Choose the **BEST TGA** for **YOUR NEEDS**

Instrument Features	TGA 55	TGA 550	TGA 5500
Low Mass IR Furnace	—	—	●
Hi-Res TGA™	—	○	●
Modulated TGA™	—	○	●
Auto-Stepwise TGA	●	●	●
DTA Signal	—	○	●
Auto-loader	●	●	—
25-Position Autosampler	—	○	●
Sealed Pan Punch	—	○	●
Color App-Style Touch Screen	●	●	●
Long-Life Wire Wound (Pt/Rh) Furnace	●	●	—
EGA Furnace Capable	○	○	●
Dual Input Gas-Delivery Manifold	●	●	●
Integrated Electromagnet	—	—	●
Temperature Calibration Curie Point (ASTM E1582)	●	●	●
Temperature Calibration Melting Point Standards	—	○	●
Blending Gas Delivery Module	—	○	○
Heated EGA Furnace Adapter	—	—	○
TGA/MS Operation	○	○	○
TGA/FTIR Operation	○	○	○
TGA/GC Operation	○	○	○

● Included ○ Optional — Not Available

INSTRUMENT AND PAN SPECIFICATIONS

Instrument Specifications	TGA 55	TGA 550	TGA 5500
Temperature Range	Ambient to 1000 °C	Ambient to 1000 °C	Ambient to 1200 °C
Temperature Accuracy	±1°C	±1°C	±1°C
Temperature Precision	±0.1°C	±0.1°C	±0.1°C
Heating Rate (Linear)	0.1 to 100 °C/min	0.1 to 100 °C/min	0.1 to 500 °C/min
Peak Heating Rate (Ballistic)	>600 °C/min	>600 °C/min	>1600 °C/min
Furnace Cooling (Forced air/N2)	1000 °C to 50° C in <12 min	1000 °C to 50 °C in <12 min	1200 °C to 35 °C in <10 min
Sample Weight Capacity	1000 mg	1000 mg	1000 mg
Dynamic Weighing Range	1000 mg	1000 mg	1000 mg
Weighing Precision	±0.01 %	±0.01 %	±0.01 %
Resolution	0.1 µg	0.1 µg	<0.1 µg
Weight Baseline Drift[1] (Ambient to 1000 ˚C)	<25 µg	<25 µg	<10 µg
Vacuum	50 µTorr (EGA furnace)	50 µTorr (EGA furnace)	50 µTorr

[1] Without baseline subtraction

All TA Instruments furnaces are covered by the industry's only **5 YEAR WARRANTY**

Pan Specifications

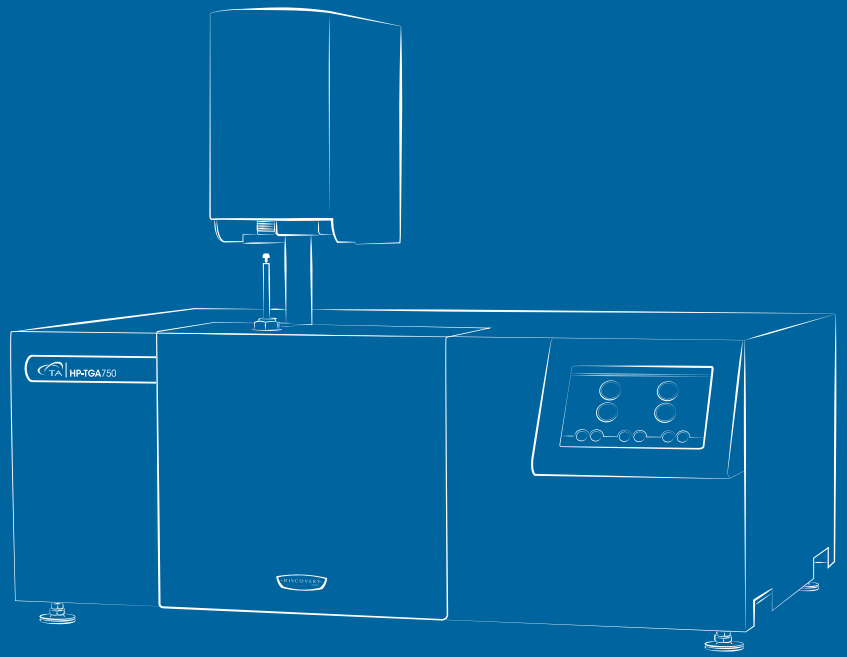
Material	Size	Temperature Range	Notes
Platinum	50 µL 100 µL	Ambient to 1000 °C	Robust, high performance, reusable pans
Ceramic	100 µL 250 µL	Ambient to 1200 °C	Reusable pans for higher temperatures
Aluminum	80 µL	Ambient to 600 °C	One-time use, can be sealed to prevent volatilization before experiment
Copper	80 µL	Ambient to 1000 °C	One-time use, can be sealed to prevent volatilization before experiment
Al Smart-Seal	35µL	Ambient to 600 °C	One-time use, can be sealed, opens automatically T-controlled at 55 ˚C inside the TGA furnace

HIGH PRESSURE TGA SYSTEMS for MEASUREMENTS UNDER EXTREME CONDITIONS

High Pressure

High Temperature

Corrosion Resistant



DISCOVERY HP-TGA | HIGH PRESSURE TGA

TA Instruments invites you to experience two new high pressure thermogravimetric (HP-TGA) instruments, the Discovery HP-TGA 75, HP-TGA 750, and HP-TGA 7500. From the world leader in Magnetic Suspension Balance (MSB) technology for over 20 years comes an ingeniously designed, user-friendly top-loading microbalance with unprecedented performance. In addition, the Discovery HP-TGA's are the first available in a convenient benchtop design and feature on-board gas dosing and blending systems, temperature control to 1100°C, One-Touch-Away™ functionality, and TA's powerful TRIOS software. Getting great high pressure data has never been so easy!

Features and Benefits:

- Patented* top-loading magnetic levitation balance enables sealed environment for thermogravimetric testing in reactive atmospheres under high pressure (up to 80 bar) and high temperatures (up to 1100°C)
- Unrivaled 0.1 µg balance resolution provides the most accurate measurements of small samples or materials with rapid reaction kinetics
- Top-loading balance design ensures superior weight stability at high temperature and pressure, and provides convenient access to sample for easy loading/unloading
- Integrated gas dosing & pressure control eliminates need for a separate system and enables a compact footprint
- Highly accurate balance temperature control for optimized baseline stability
- Non-porous isolation material in contact with the reaction gas within the furnace eliminates potential retention of gases ("memory" effect) and enables rapid attainment of vacuum
- Curie-point calibration eliminates the effects of the reaction gas type and pressure on the temperature measurement
- Compact design puts high pressure TGA on the benchtop, minimizing valuable lab space requirements and enabling installation in a fume hood to easily manage ventilation when working with toxic gases
- High heating and cooling rates (~200 K/min**), even under high pressure, reduces potential for unwanted side reactions and improves sample throughput
- Small internal volume allows for rapid gas changes and quick pressurization, low gas consumption, and safe operational conditions due to the small quantity of compressed gas

* European Patent: 1958323, U.S. Patent: 2009/0,160,279 Al, German Patent: DE 10 2015 116 767.0

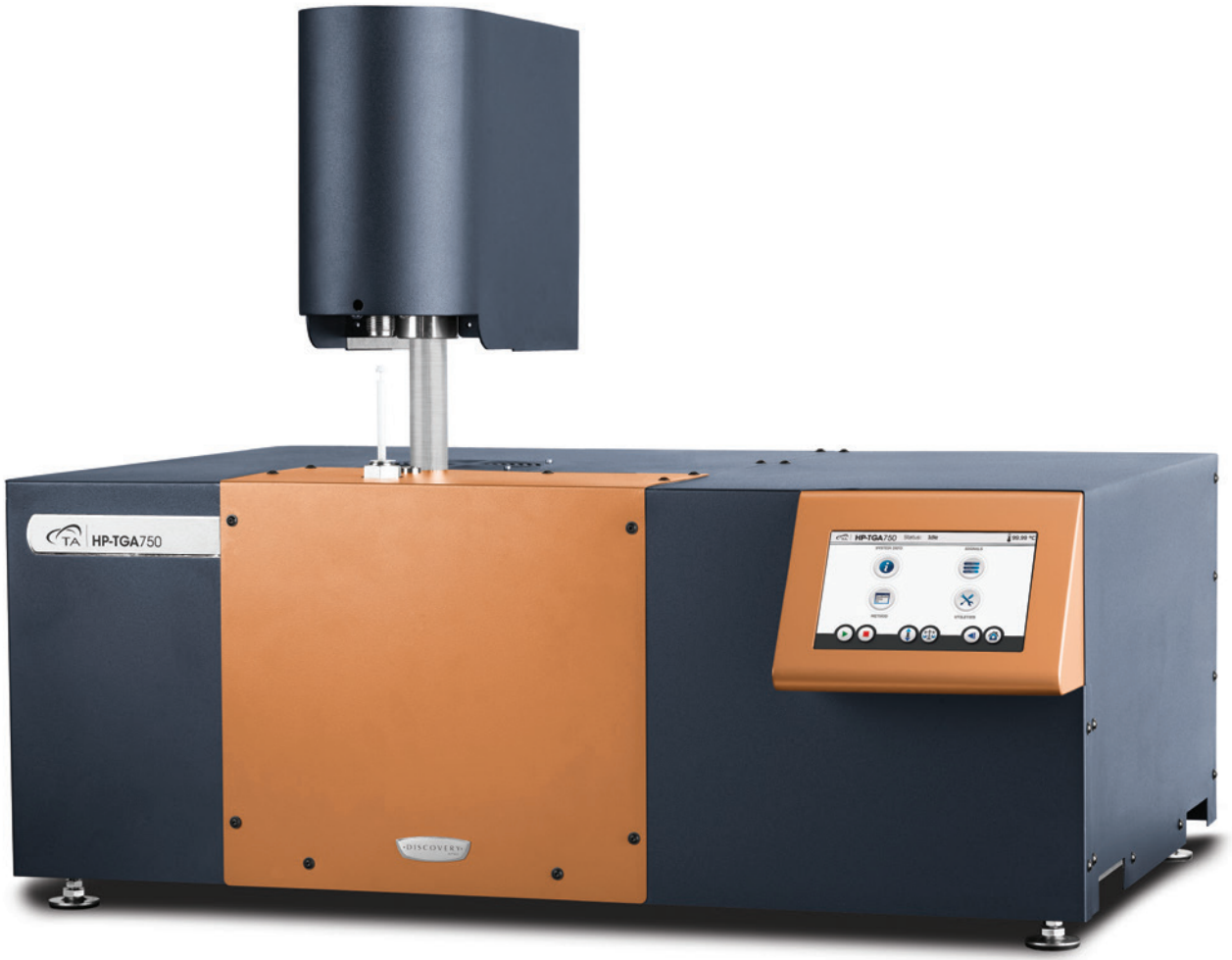
** Cooling rate at ~200 K/min possible when at T ≥ 300°C

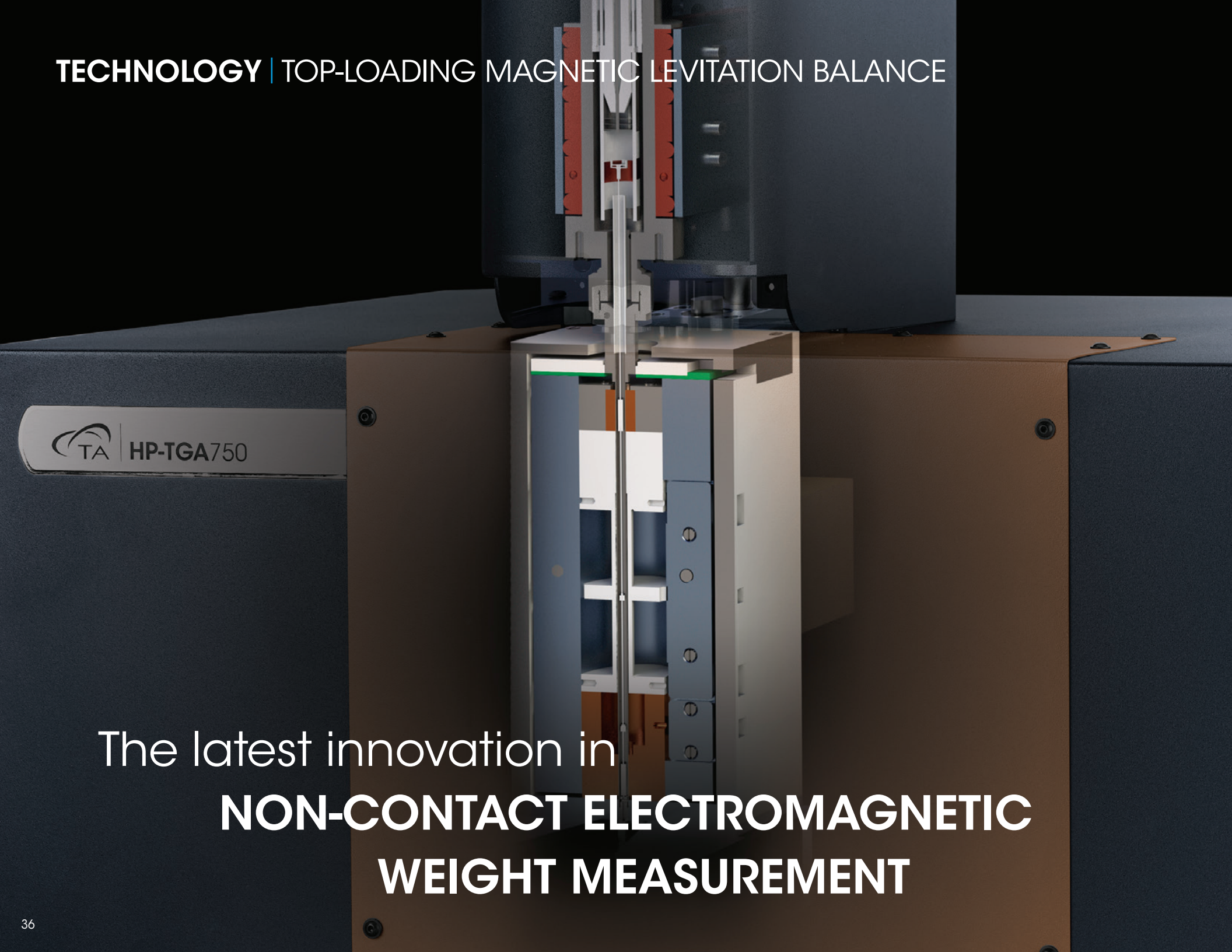
The world's first

BENCHTOP HIGH PRESSURE TGA

featuring patented

TOP LOADING MAGNETIC SUSPENSION BAL-ANCE





The latest innovation in

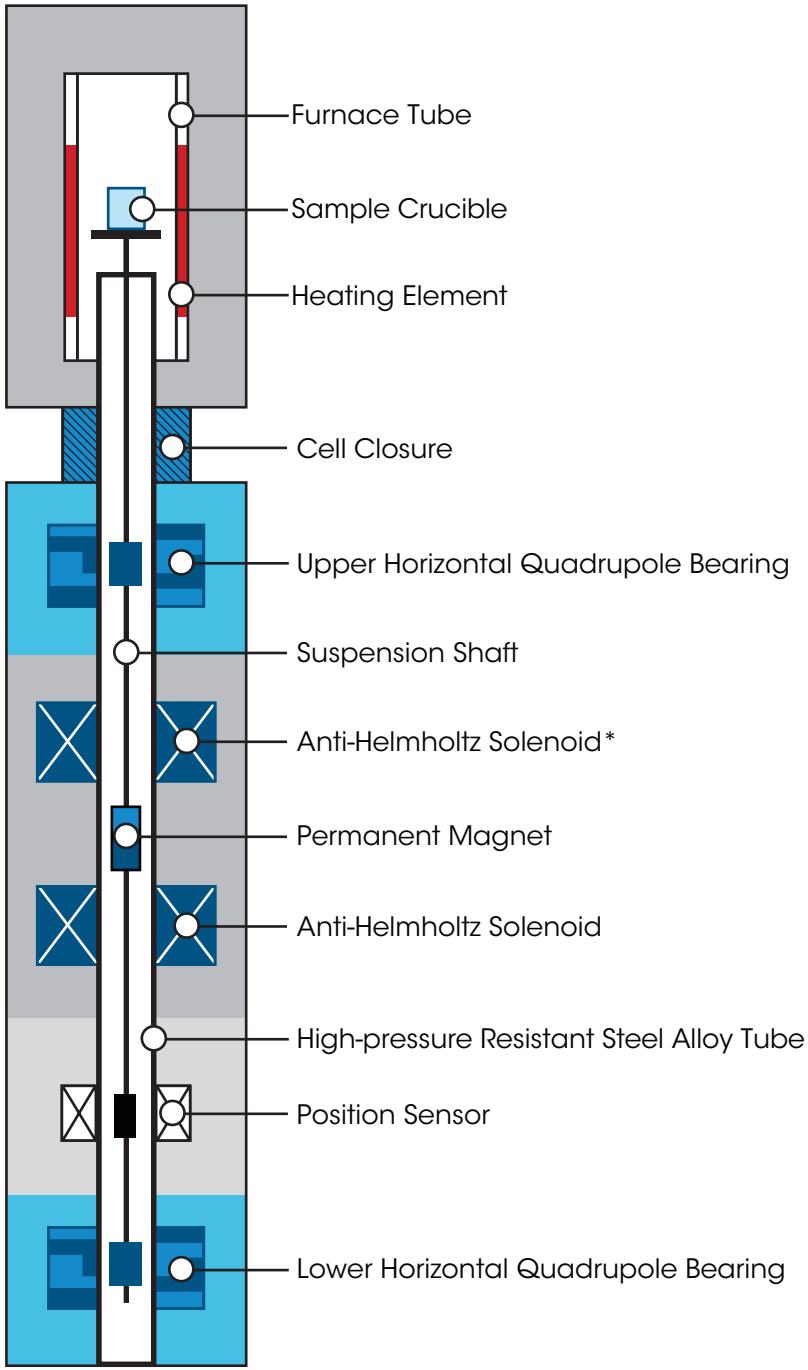
NON-CONTACT ELECTROMAGNETIC WEIGHT MEASUREMENT

At the core of every Discovery HP-TGA is the new top-loading magnetically-levitated (MagLev) balance. Multiple patented* technologies are combined to bring to life a highly sensitive and compact balance that can operate under high pressure and high temperature.

How it Works

Within the Mag-Lev Balance, a small-diameter high pressure-resistant steel alloy tube encloses a suspension shaft and crucible setup. A dual Anti-Helmholtz coil array, LVDT electronic sensor coils and the quadrupole magnet assembly are outside of the tube. The Anti-Helmholtz coils generate an extremely uniform electromagnetic field which levitates a permanent magnet attached to the suspension shaft. A platform at the top of the shaft holds the sample crucible. The suspension shaft is centered horizontally inside the tube by patented 2D magnet quadrupole bearing rings located at the top and bottom of the shaft. The vertical location of the permanent magnet is held constant via a control feedback loop between the Anti-Helmholtz coils and an LVDT position sensor with sub-micron resolution located on the shaft below the magnet. The amount of current that is delivered to the coils in order to maintain a constant position of the magnet is proportional to the weight of the shaft, magnet, and crucible. This weight is set to zero through a balance tare. When a sample is added to the crucible, the current required to maintain the balance position is now proportional to the sample weight.

In this configuration, the components contained within the small-volume tube are completely sealed off from the outside. The electronmagnetic coils and other sensitive parts are located outside of the tube and operate under normal atmospheric conditions to generate the electromagnetic levitation force through the pressure-resistant tube. Only the sample crucible and other components within the small-volume tube need to be pressurized and can be exposed to a variety of gases or gas mixtures. This complete separation of the balance electronics from the reaction atmosphere enables TGA measurements to be performed from vacuum to high pressures using toxic, corrosive and explosive reaction atmospheres.



* Solenoid = Coil wound in a straight hollow helix.

* European Patent: 1958323, U.S. Patent: 2009/0,160,279 Al, German Patent: DE 10 2015 116 767.0

TECHNOLOGY | HIGH PRESSURE FURNACE & INTEGRATED GAS DOSING

ADVANCED REACTION FURNACE DESIGN for OPTIMAL TEMPERATURE and PRESSURE CONTROL

An innovative high-pressure reaction furnace for the most accurate and responsive temperature control under ALL pressure and gas flow conditions.

At the core of the Discovery HP-TGA furnace is a robust corrosion-resistant ceramic tube with an embedded platinum heating element capable of temperature control to 1100°C*. Sample temperature is measured by a thermocouple within the heater tube directly adjacent to the sample. The compact, low-mass design is highly responsive and capable of heating/cooling rates of up to 200°C/min. The ceramic heater tube is contained within a pressure vessel which enables characterizing samples to 80 bar. Testing can be performed in corrosive reaction atmospheres and, as no porous material is in contact with the atmosphere, changing of the reaction gas is clean, fast, and without any memory effects. The Discovery HP-TGA is the only high pressure TGA to feature Curie-point temperature calibration at any pressure and with any reaction gas. HP-TGA temperature calibration has never been so easy.

* Maximum temperature obtained with N_2 and other reaction gases with similar heat conductivity

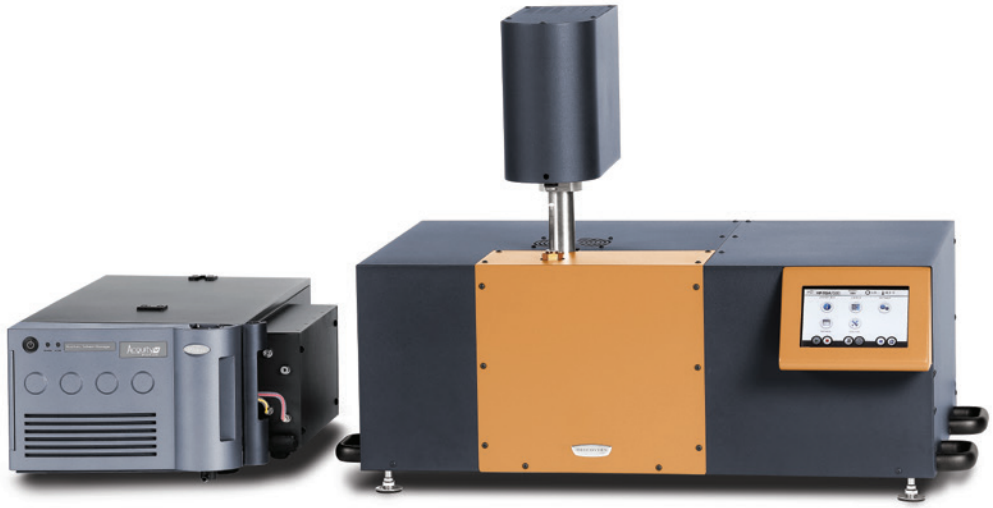
Integrated Gas and Steam Dosing and Blending Systems with Pressure Control

In high pressure TGA, the reliability and accuracy of gas flow and pressure control is of utmost importance for the data quality. All Discovery HP-TGA models feature integrated gas dosing and blending systems with pressure control to provide the flexibility to address the widest range of applications. Pressure can be controlled in the range from 200 mbar to 80 bar and complete evacuation to ultimate vacuum is possible as well. All Discovery HP-TGA instruments include a mass flow controller connected to an inert gas for the balance purge.

The **Discovery HP-TGA 75** is equipped with a single reaction gas mass flow controller and three gas connections. One reaction gas can be selected from the three connected. During a measurement, the reaction gas can be switched through software controls.

The **Discovery HP-TGA 750** is equipped with three reaction gas connections and three independent reaction gas mass flow controllers, which enables the reaction gas to be a pure gas or a blend of up to three gases.

The **Discovery HP-TGA 7500** is additionally equipped with a high-pressure steam generator. An accurate HPLC pump controls a flow of liquid water into an evaporator where the steam is generated. The steam is mixed with the reaction gas or gas mixture coming from the reaction gas mass flow controllers. Anti-condensation heating enables measurement with high steam concentrations at high pressures without unwanted condensation.



TGA analysis under **CONTROLLED PROCESS ATMOSPHERES** with integrated **GAS AND STEAM DOSING SYSTEMS** and **PRESSURE CONTROLLER**

TECHNOLOGY | "APP" STYLE TOUCH SCREEN

One Touch Away™

Powerful HP-TGA performance at your fingertips

The HP-TGA boast a brand-new One-Touch-Away™ app-style touch screen that greatly enhances usability by placing key instrument features at your fingertips.

Touch Screen Features and Benefits:

- Ergonomic design for easy viewing and operation
- Packed with functionality to simplify operation and enhance user experience. The app-style touch screen includes:
  - Start/stop runs
  - Real-time plot
  - Curie point temperature calibration
  - Test and instrument status
  - Active method viewing
  - Loading/unloading samples
  - Real-time signals
  - Advance method segments
  - System information

WITH ONE-TOUCH-AWAY, IT'S NEVER BEEN EASIER TO GET GREAT HIGH PRESSURE DATA!

TECHNOLOGY | TRIOS SOFTWARE

Discover powerful TRIOS software that delivers exceptional user experience in a combined package for instrument control, data analysis and reporting for thermal analysis and rheology. New features such as multiple calibration sets, real-time test method editing, and inter-laboratory data and test method sharing provide unmatched flexibility, while one-click analysis and custom reporting raise productivity to new levels.

TRIOS Features:

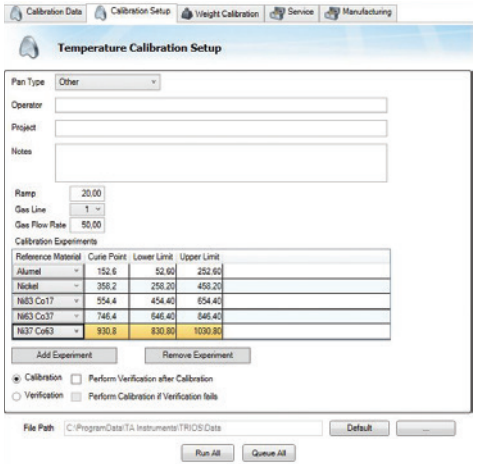
- Control multiple instruments with a single PC and software package
- Overlay and compare results across techniques including DSC, TGA, DMA, SDT and rheometry
- One-click repeated analysis for increased productivity
- Automated custom report generation including: experimental details, data plots and tables, and analysis results
- Convenient data export to plain-text, CSV, XML, Excel®, Word®, PowerPoint®, and image formats
- Optional TRIOS Guardian with electronic signatures for audit trail and data integrity

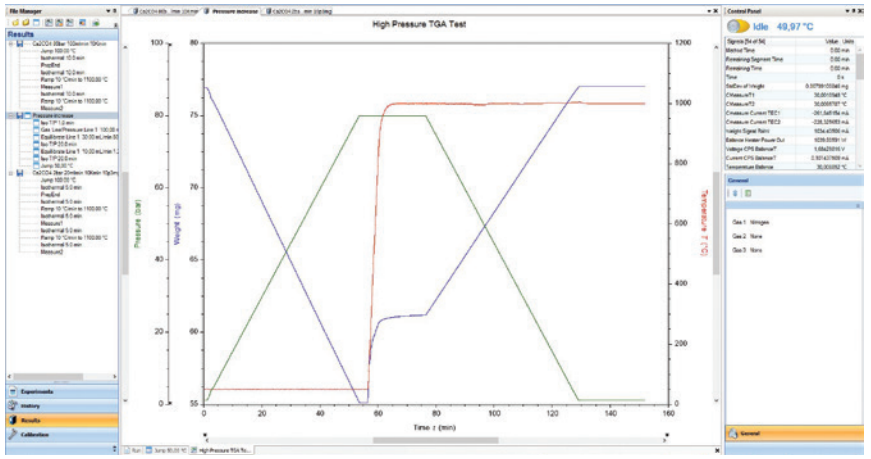
Ease of Use

TRIOS software makes calibration and operation of the entire line of Thermogravimetric Analyzers simple. Users can easily generate Curie-point temperature calibration data sets under varying experimental conditions (e.g. different pressures or gas selections) which are automatically applied to match the experimental conditions used for sample testing. Real-time signals and the progress of running experiments is readily available with the added capability of modifying a running method on the fly. TRIOS software offers a level of flexibility that is unmatched in the industry.

Complete Data Record

The advanced data collection system automatically saves all relevant signals, active calibrations, and system settings. This comprehensive set of information is invaluable for method development, procedure deployment, and data validation.





The Most **VERSATILE CONTROL** and **ANALYSIS SOFTWARE**

Complete Data Analysis Capabilities

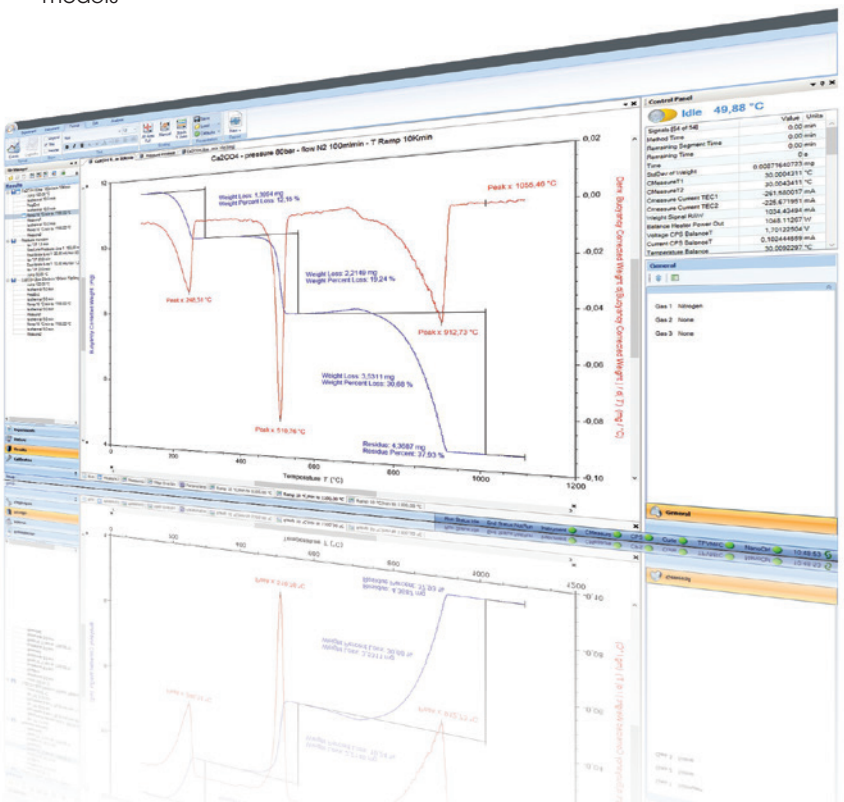
A comprehensive set of relevant tools are available for real-time data analysis, even during experiments. Gain actionable insights into material behavior through a powerful and versatile set of features seamlessly integrated into TRIOS.

All Standard TGA Analyses:

- Weight change (absolute and as a percentage)
- Residue content
- 1st and 2nd derivatives
- Weight at a specified time or temperature
- Weight loss at a specified time or temperature
- Peak height and area
- Temperature at peak maximum
- Onset and endset analyses
- Step transition analysis
- Easily import and export TGA data with TRIOS

Advanced Analysis Capabilities:

- Decomposition kinetics
- Advanced custom analysis with user-defined variables and models



TRIOS JSON Export Feature

Powerful human- and machine-readable data in an open standard

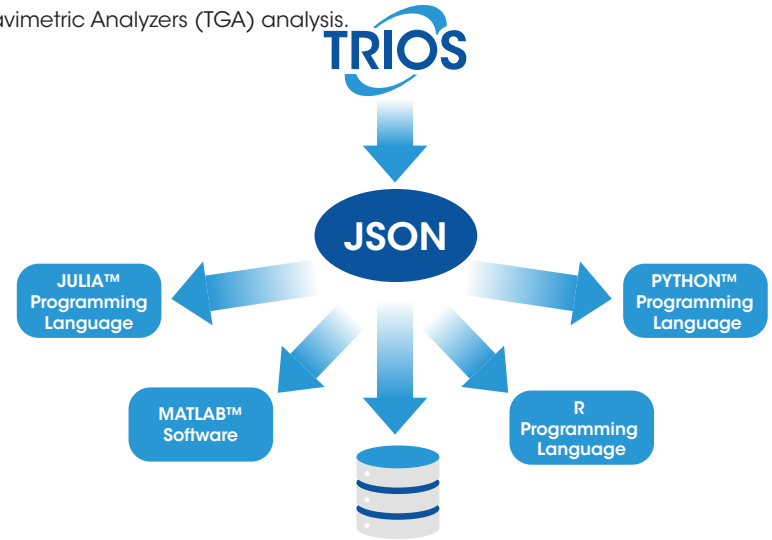
Unlock the power of your Thermogravimetric Analyzers (TGA) data with the TA Instruments™ TRIOS JSON Export Feature, designed to revolutionize data management and utilization. This powerful new capability seamlessly integrates TRIOS Software data with data science tools, automation workflows, and lab systems such as LIMS, making data handling more efficient and accessible than ever before.

Key Features:

- **Seamless Integration:** Convert your TRIOS data into the open standard JSON format, JSON is available:
  - Automatically on every save (enabled in options)
  - Through manual export dialogs
  - As part of the "Send to LIMS" functionality
  - Via the "Batch" processing dialog or from the command line
  - In TRIOS AutoPilot
- **Data Consistency:** Our publicly available JSON schema helps ensure a consistent data structure, allowing you to write code once and apply it almost universally across most of your data files.

- **Python Library:** Open-sourced Python Library, TA™ Data Kit (available at github.com/TA-Instruments/tadatakit), to simplify your data ingestion or learn how to take advantage of the power of our data with our code examples.

With the TRIOS JSON Export Feature, you're not just collecting data – you're unlocking its full potential. Experience streamlined workflows, reliable results, and a community-driven approach to Thermogravimetric Analyzers (TGA) analysis.



The DISCOVERY HP-TGA is Uniquely Suited for Challenging THERMOGRAVIMETRIC APPLICATIONS

- High Temperature Corrosion
- Coal & Biomass Gasification
- CO_2 and CH_4 Getter Materials
- Pyrolysis Processes
- Catalyst Materials (TPx, Sulphidation, Coking)
- CVD Coating Processes
- Decomposition & Degradation Reactions

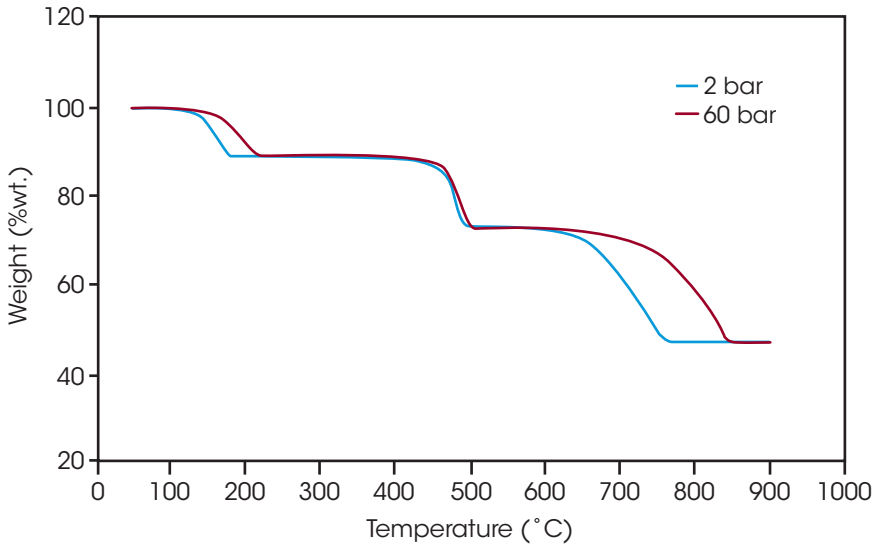
Weight Loss of Calcium Oxalate under Varying Conditions

Calcium Oxalate is a widely characterized material with very well-known and understood weight loss behavior. It undergoes three discrete decomposition events, each with a pronounced step change in weight. The onset of the weight change associated with each decomposition is affected by sample mass, heating rate, and pressure. The magnitude of the weight changes, as a percent of total starting weight, should not change with these variables.

In standard thermogravimetry measurements (TGA), the onset of decomposition can be studied under variable mass and heating rate. However, with the TA Instruments high pressure TGA (HP-TGA), measurements can be conducted as a function of all three variables (mass, heating rate, and pressure).

In the figure to the right, two Calcium Oxalate decomposition measurements in Ar at 2 bar and 60 bar pressure are compared. While the decomposition temperatures of the three steps are all shifted to higher temperatures at high pressures, the weight changes in each decomposition step are identical.This illustrates the kinetic nature of decomposition. Varying the pressure, heating rate, or initial sample mass will impact the temperature at which a material decomposes.

Calcium Oxalate Decompostion in Ar at 2 bar and 60 bar



Pyrolysis and Gasification

Coal, biomass, recycled polymer waste and other organic materials are gasified for energy utilization or as alternative feedstock. Such processes can be measured under application-relevant conditions in the Discovery HP-TGA. The first step in a gasification process is pyrolysis of the raw material, where, while heating the organic material in an inert atmosphere (eg. N_2 or Ar), volatile components (water, hydrocarbons, tar) are evaporated and char is generated. Gasifying this carbon-rich char as a second reaction step requires a gasifying agent.

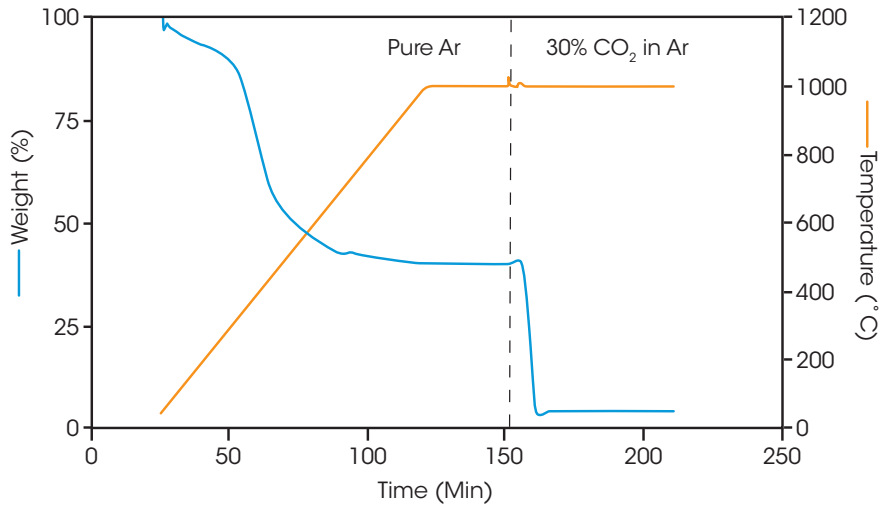
The gasification agent carbon dioxide and the carbon char generate carbon monoxide gas according to the following main reaction:

$$CO_2 + C \rightarrow 2CO$$

Additional gases can be products of further or incomplete conversions and side reactions.

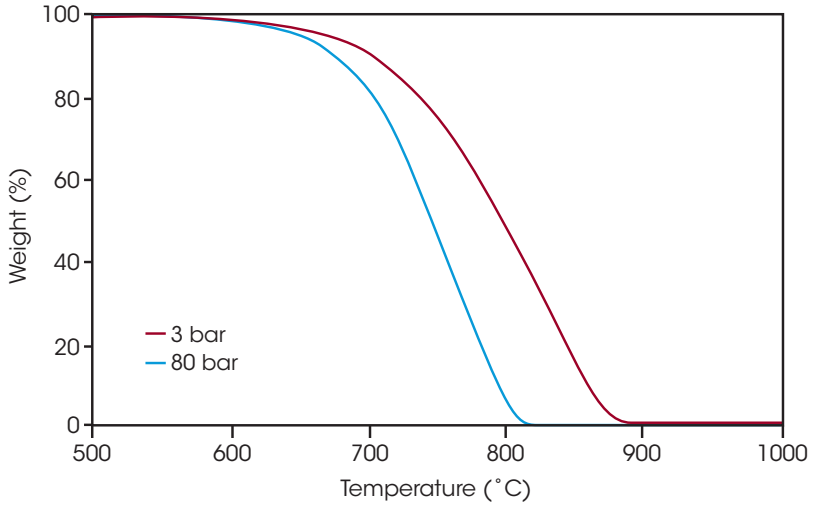
Because the process reaction kinetics depend on the reaction conditions and the raw material, the composition and pressure of the gases generated will vary. Discovery HP-TGA instruments allow optimization of operating conditions for a given raw material. In addition, they can be equipped with a mass spectrometer for evolved gas analysis.

In the figure to the right, the pyrolysis and gasification process of a lignite at 30 bar measured with the Discovery HP-TGA is shown. During heating to 1000°C at a heating rate of 10°C/min,



Graphite Oxidation

Burning of solid or liquid fuels is an oxidation process. The oxidation temperature and the reaction kinetics depend on the pressure and the oxygen content of the reaction gas. With the Discovery HP-TGA the influence of pressure and oxygen concentration on the oxidation can be studied. In this example, graphite was oxidized in air at 3 bar and at 80 bar. The data in the figure to the right show that at the higher pressure of 80 bar, the reaction comes to completion at a much lower temperature compared to the experiment at lower pressure. The ability to complete a reaction with lower energy input can save significant cost in manufacturing processes. Some relevant applications include pressurized fluidized bed power plant design and underground coal gasification.

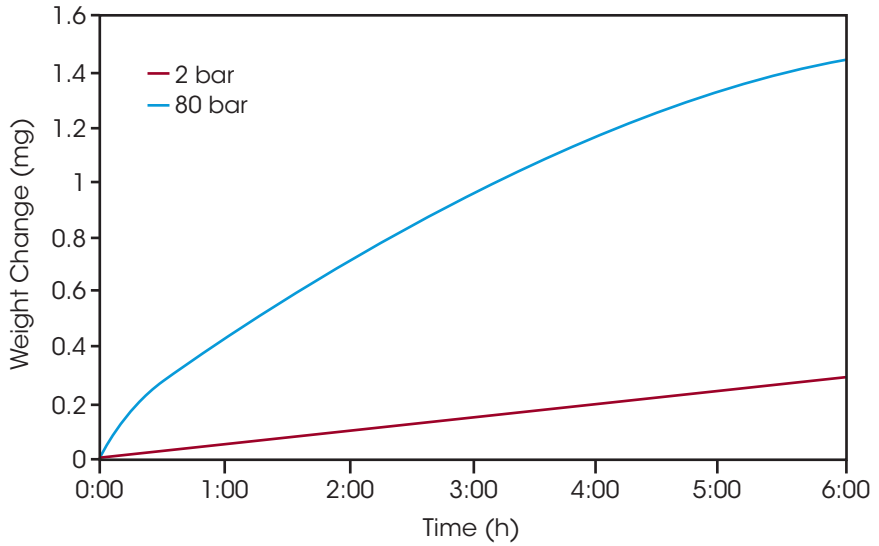


DISCOVERY how
PRESSURE can change the
REACTION KINETICS

DISCOVERY more about the **PRESSURE DEPENDENCE** of your **MATERIALS**

High Temperature Corrosion

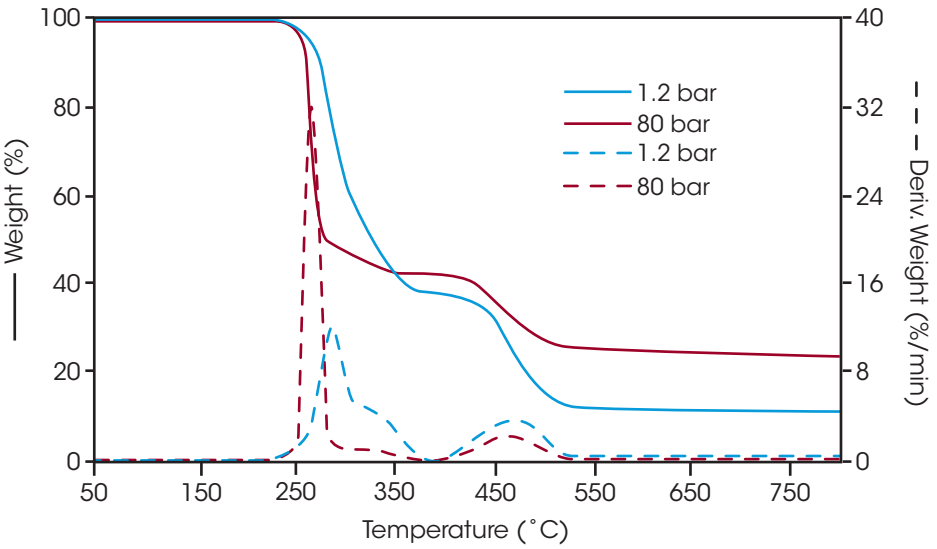
Understanding the corrosion resistance of a material can be critical for improving technical processes and increasing efficiency. For example, the efficiency of gas or steam turbines and jet engines is directly related to their maximum operation temperature. The maximum temperature is limited by the high-temperature corrosion of the materials used. The mass change of a metal or other material caused by corrosion is generally very small. Additionally, even high temperature corrosion is usually a slow process. The Discovery HP-TGA is ideally suited for such measurements because the exceptional high resolution and accuracy allows measurement of small changes in sample mass over a comparably short period of time. The figure to the right compares the mass increase of a Inconel®* C-276 alloy in air at 1000°C at 3 bar and at 80 bar. The observed weight gain is caused by oxidation of the alloy's surface. The total mass change here is about 287 µg at 3 bar and 1444 µg at 80 bar. As expected, the pressure of the corrosive atmosphere has an influence on the kinetics of, and amount of, corrosion.



* INCONEL® is a trademark of Huntington Alloys Corporation, Huntington, WV 25705, United States of America

PVC Decomposition

Thermal decomposition of polymeric materials is a routine thermogravimetric test. The new Discovery HP-TGA enables the added dimension of understanding the influence of pressure on decomposition temperatures and kinetics. This information is critical to define the limits of operation which should not be exceeded during manufacturing or applications. Polymer materials can be tested under real-world conditions using the actual pressures and reaction gases of interest. In the figure to the right, the decomposition of PVC-P in nitrogen gas is compared at pressures of 1.2 and 80 bar. The decomposition is a multistage process. Typically HCL, aliphatic and aromatic hydrocarbons are the decomposition products. At higher pressure, the kinetics of the first step of decomposition is much faster compared to the measurement at ambient pressure. The following decomposition steps are more clearly separated than at low pressure. Decomposition temperature is not significantly changed by the higher pressure. At 80 bar however, a residue of ca. 23%wt is remaining after the decomposition while at ambient pressure only 10% of the PVC is not decomposed.



HIGH PRESSURE TGA | INSTRUMENT SPECIFICATIONS

Product Line	Model	Max. Sample Temperature	Maximum Pressure	Weighing Resolution	Weighing Range / Sample Mass	Reaction Atmosphere
Discovery HP-TGA	75	1100 °C	80 bar	0.1 µg	500 mg / 500 mg	Pure Gas (select and switch between 1 of 3)
	750	1100 °C	80 bar	0.1 µg	500 mg / 500 mg	Pure Gas & Gas Blends (of 3 gases)
	7500	1100 °C	80 bar	0.1 µg	500 mg / 500 mg	Pure Gas & Gas Blends & Gas and Steam Blends (of 3 gases and 1 steam)

*Maximum pressure is temperature dependent

HIGH PRESSURE TGA, UNPRECEDENTED EXPERIMENTATION

AMERICAS

New Castle, DE USA
Lindon, UT USA
Wakefield, MA USA
Eden Prairie, MN USA
Chicago, IL USA
Irvine, CA USA
Montreal, Canada
Toronto, Canada
Mexico City, Mexico
São Paulo, Brazil

EUROPE

Hüllhorst, Germany
Eschborn, Germany
Elstree, United Kingdom
Brussels, Belgium
Etten-Leur, Netherlands
Paris, France
Barcelona, Spain
Milano, Italy
Warsaw, Poland
Prague, Czech Republic
Solna, Sweden
Copenhagen, Denmark

ASIA & AUSTRALIA

Shanghai, China
Beijing, China
Tokyo, Japan
Seoul, South Korea
Taipei, Taiwan
Guangzhou, China
Petaling Jaya, Malaysia
Singapore
Bangalore, India
Sydney, Australia

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