Malvern Panalytical

Catalysis

Comprehensive characterization

Catalysis at the heart of modern industry

Over 85% of all chemical products rely on catalysis. As industries respond to sustainability, efficiency, and circular-economy initiatives, catalyst R&D is rising to meet these challenges and opportunities. From sustainable aviation fuel (SAF) and CO_2 utilization to hydrogen production, biomass conversion and advanced chemicals, success depends on understanding catalyst structure, chemistry, and performance in detail.

Digital catalysis is seeing significant growth with AI, machine learning and automated analysis coming together to predict structure / reactivity relationships, cut down on trial and error testing and provide data that can be readily accessible for future studies – FAIR data. Catalyst development and manufacture demand insight across physical structure, chemical composition, and functional performance.

Malvern Panalytical supports this new era of catalysis with analytical solutions that connect material properties to real-world performance. Our combined portfolio delivers comprehensive solutions to support R&D, quality control and scale-up with complementary techniques that work together and offer extended insight.

Scan the QR code to find out more

Surface area & porosimetry

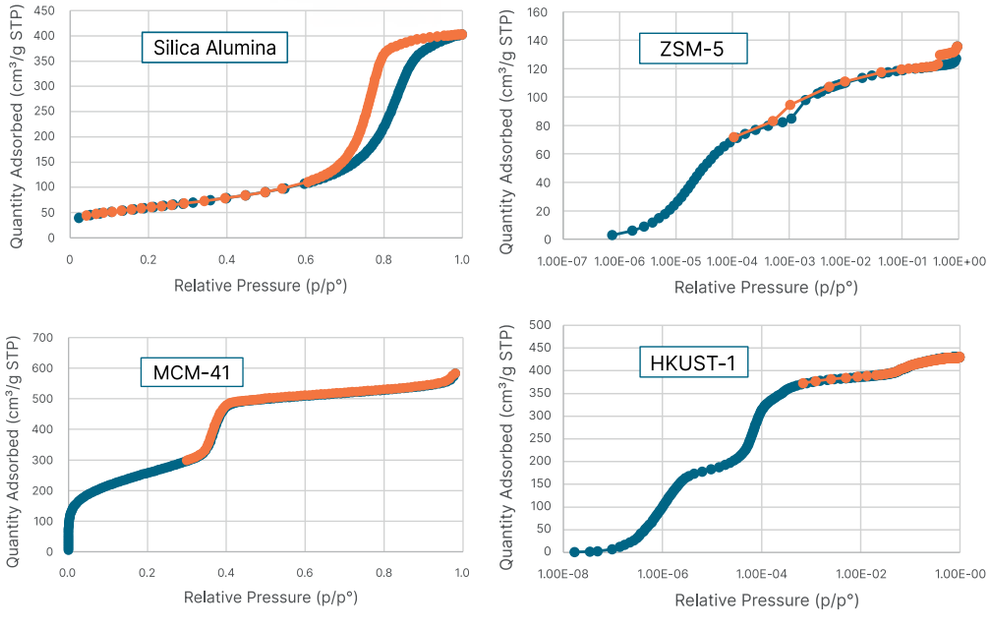
Understanding catalyst support pore structure and behavior

From simple single station to high throughput micropore analysis we have a variety of solutions to meet your needs. Determine pore sizes from 0.35 – 500 nm and no upper limit on surface area.

MicroActive provides a common platform across the Micromeritics range and offers capability and flexibility for both new and experienced users. A Python interface offers further flexibility, allowing for bespoke reports to be generated. As soon as an experiment completes, data can be automatically exported to a network repository or LIMS system making it instantly available to a wider group driving both QC needs and R&D progress.

BET surface area, micro and meso pore size using classical and NLDFT techniques. Advanced features such as automated BET fit using Rouquerol criteria and pore size determination by combing N_2 and CO_2 isotherms all driven by our MicroActive software. Data optimization is fast and easy via a Graphical User Interface within our powerful MicroActive software platform.

Sample preparation is critical and we never share vacuum sources with the analysis side of the instrument. Options from manual flowing gas to computer controlled multi step high vacuum are there to meet your needs.



Exceptional isotherm resolution across the whole micro / meso pore size range

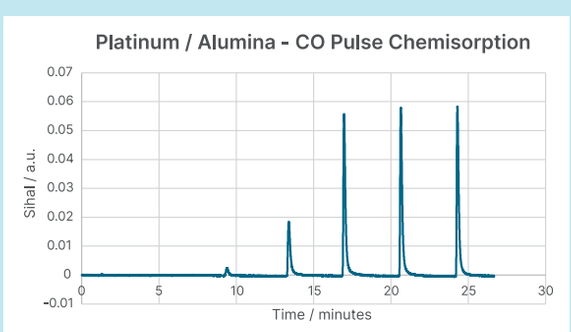
Chemisorption

Quantifying active site concentration and performance.

The **3Flex** is our top of the range gas porosimeter offering high resolution micropore analysis. This technology also offers models for static chemisorption for metal surface area and dispersion using the repeat isotherm technique as well as a dynamic version for temperature programmed studies and pulse chemisorption. This versatile offering can sequence experiments allowing the user to see how chemisorption experimentation affects physical properties such as area and pore volume.

The **AutoChem III 2930** and **ChemiSorb Auto** are our dynamic chemisorption technologies. The AutoChem III 2930 offers exceptional flexibility with 18 gas inlets, vapor capability and is available with our Enhanced Corrosion Resistance (ECR) technology making it the ideal choice for R&D groups with wide ranging needs. The ChemiSorb offers exceptional price / performance and can perform all routine temperature programmed (TPx) and pulse chemisorption experiments required by QC departments.

Metal area and dispersion together with pore size and volume are key to reaction rate through reactant delivery and product removal. Chemisorption allows us to establish activation conditions, understand reactivity with respect to supports and promoters as well as study deactivation



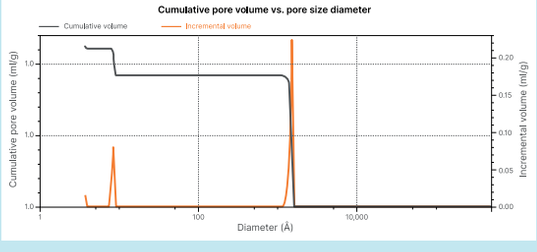
Fully automated pulse chemisorption to determine dispersion, metal surface area and crystallite size

Mercury porosimetry & porometry

Meso / macro & through pore size analysis.

Many catalysts rely on hierarchical pore systems for mass transport. Catalytic materials can include micro, meso and macro pores. Characterising the complete pore size distribution is important. If we consider an acid catalyst like zeolite ZSM-5 then it displays all of these pore size classes and the larger meso and macro pores are the main conduits along which reactants enter and products leave. The micropores are where the active sites are located. Micromeritics offers the facility to combine gas and mercury data to provide a 'Unified method for Total Pore Volume' and attribute areas and volumes based on IUPAC pore size classifications. See also ISO 15901.

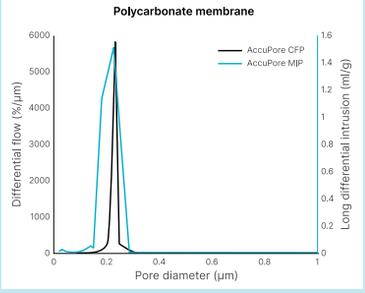
Working with films / membranes? **Capillary Flow Porometry (CFP)** is the way to quickly and easily determine through pore size distributions. The **AccuPore** technology determines through pore sizes from 13 nm to 500 µm and offers both scanning and equilibrated analysis routines. Other features include smart gas management and simple touchscreen operation. High resolution data collection means that curve fitting is avoided.



Pore Volume (ml/g)	
Total	1.118
Macro (>500 Å)	0.916
Meso (20 to 500 Å)	0.000
Micro (<20 Å)	0.202

Pore Area (m^2/g)	
Total	1049.203
Macro (>500 Å)	24.753
Meso (20 to 500 Å)	0.014
Micro (<20 Å)	1024.435

The Unified Method for Total Pore Volume allows you to combine gas and mercury porosimetry data and define area and volumes based on IUPAC pore size criteria.



Analysis of this polycarbonate membrane by both porometry and mercury porosimetry reveals very similar mode sizes but the porometry data shows a significantly narrower distribution when just the through pores are considered relative to the overall porosity quantified by mercury porosimetry.

Reactor technology

From bench scale insight to pilot scale confidence.

Single and dual station reactors with flexible options allow a wide range of industrially important chemistries to be studied including reforming. Fischer Tropsch, Haber Bosch, gasification, pyrolysis and more. With patented technologies including gas liquid (*) separation and fast acting pressure control the **FR series** is a chemical plant on the bench!

* Gas / liquid / liquid also available for FT reactions

With focus on synthetic fuels and particularly SAF from various carbon waste streams such as plastics, wood and biomass, pilot plants offer scale up of innovative technologies to provide the understanding and data that enables commercialization.

Solid / gas & liquid feeds, exceptional pressure and temperature control with a choice of separation technologies we are well placed to take your process beyond the lab bench.

The **ICCS**, In-situ Catalyst Characterization System uniquely offers the ability to carry out dynamic and pule chemisorption routines in-situ. Perform in reactor analysis at the start and end of the reaction cycle, to understand performance and deactivation issues. The ICCS is usable with a wide range of flow reactors.

Pilot Plant

Pilot Plant is a crucial step in scaling up towards plant design and implementation. Our long experience in pilot plant design and manufacture allows us to offer pilot plant covering traditional crude oil fractionation (MAT tester), pressure / temperature swing adsorption, gasification and pyrolysis as well as GTL technology and photocatalysis.

Biomass - Solid feed pyrolysis / gasification unit - synthetic liquid product

Biomass reactor then FT to synthetic fuels

Ammonia synthesis unit

Pressure swing adsorption / temperature swing adsorption. E.g. PSA with zeolite 13X for O_2 / N_2 separation

X-ray diffraction (XRD)

Phase identification and structural evolution.

X-ray diffraction (XRD) is essential for understanding how the crystalline structure of catalysts governs their performance and reaction pathways. Malvern Panalytical's Aeris and Empyrean systems provide powerful, accessible solutions for routine catalyst quality control, but especially for advanced R&D.

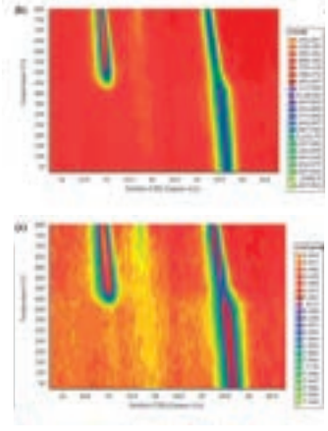
Empyrean is the only XRD system capable of measuring all sample types on a single instrument, and offers the broadest experimental flexibility for catalyst research

Supports advanced in-operando and in-situ studies to replicate real reaction conditions, small-angle X-ray scattering (SAXS) for probing scaffold and pore dimensions, and total scattering/PDF analysis for characterizing amorphous components.

Aeris delivers industry-ready phase analysis with minimal user expertise.

Rapid, automated workflows enable high-throughput quantification of key phases such as γ-alumina and zeolites, assessment of crystallinity, and monitoring of crystallization endpoints.

With scan times of just minutes, Aeris allows rapid optimization of processing parameters and real-time monitoring of material quality.



In-situ monitoring of the thermal response of catalyst material Fe_2O_3 and PdO/Fe_2O_3 between 250°C and 800°C using an Empyrean.

(a) plot for the two Fe_2O_3 phases showing a phase transition at ca. 450°C.

(b) plot for PdO/Fe_2O_3 shows a sharpening of the primary peak corresponding to PdO at ca. 550°C, indicating an increase in the average crystallite size of PdO and an accompanying loss of the small surface domains on the support material.

Together, Empyrean and Aeris enable comprehensive structural insights throughout the catalyst lifecycle.

X-ray fluorescence (XRF)

Elemental composition and metal loading.

X-ray fluorescence (XRF) plays a central role in catalyst development, qualification, and quality control by delivering fast, accurate elemental composition data without wet chemistry or complex sample digestion. Malvern Panalytical offers a complete XRF portfolio that supports needs ranging from high-end R&D to routine and at-line process control, allowing users to select the right balance of sensitivity, throughput, footprint, and cost of ownership.

Zetium is our flagship, floor-standing XRF platform, designed for the most demanding catalysis applications. Uniquely it can combine wavelength-dispersive and energy-dispersive XRF (WDXRF + EDXRF) to deliver maximum sensitivity and selectivity. Detection limits down to ~0.1 ppm enable reliable quantification of precious metals such as Pt, Pd and Rh, detection of catalyst poisons (Cl, S, Sn, Pb), and accurate determination of key ratios such as Si/Al in zeolites. Outstanding long-term stability supports months of operation without re-standardization, across powders, pellets, fused beads, metals and liquids.

Epsilon 1 is a compact, fully integrated benchtop EDXRF spectrometer for routine elemental analysis. It offers simple operation, minimal sample preparation and low running costs, with ppm-level sensitivity for solids and liquids. Factory-precalibrated industry solutions make it well suited to screening studies, routine catalyst checks and recycling applications.

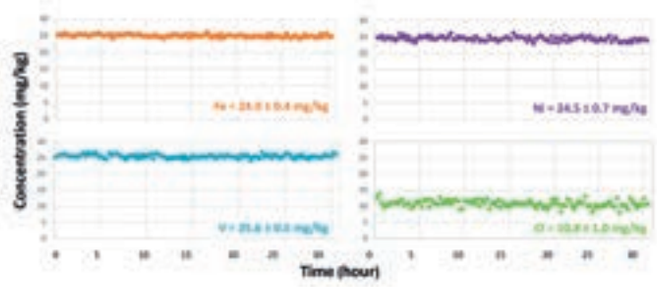
Epsilon 4 builds on the benchtop concept with higher performance and throughput for at-line and QC environments. Using advanced EDXRF technology, it analyzes elements from F to Am with ppm-level sensitivity and short measurement times, approaching the performance of floor-standing systems while maintaining a compact footprint and low infrastructure requirements.

X-ray fluorescence (XRF) (continued)

Revontium is a new, compact and automatable EDXRF spectrometer that bridges benchtop and floor-standing performance. It features an integrated 32-position sample changer and spinner for unattended batch analysis, very low energy consumption, and a patented ZETA X-ray tube that minimizes intensity drift, reducing calibration effort and maximizing uptime. Revontium is ideal where high throughput and consistency are required without the cost or footprint of traditional floor-standing XRF.

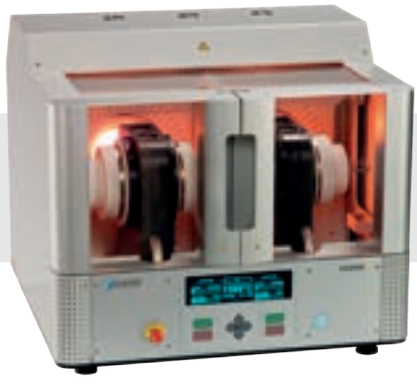
Epsilon Xflow delivers on-line multi-element analysis for liquids:

- enables continuous, real-time elemental monitoring of liquids and slurries in a flowing process stream
- ideal for monitoring slurry stoichiometry, reactor contents and catalyst inhibitor levels under harsh industrial conditions



Online XRF analysis using Epsilon Xflow. Here the abundance of four catalyst inhibitors (Fe, Ni, V and Cl) in a fluid catalytic cracking (FCC) process are tracked over 30 hours.

Claisse fusion sample preparation tools and certified reference materials ensure optimized, repeatable XRF workflows across the catalyst lifecycle.



Particle size & morphology

Particle size, shape, flowability and stability analysis.

Precise control of particle size and morphology is fundamental to catalyst performance, influencing everything from precursor precipitation, flow behavior during shaping and impregnation efficiency, to final shaping and washcoat behavior. Together, these techniques support process optimization, troubleshooting and long-term product consistency.

Malvern Panalytical's comprehensive particle toolkit delivers high-resolution, statistically robust characterization across every stage of catalyst manufacture.

Mastersizer 3000+ delivers accurate laser diffraction particle size distribution data for powders, suspensions, and emulsions.

Optimize milling, washcoat rheology, specific surface area estimation, predicting catalyst attrition and real-time process monitoring.

Measurement range: 0.01–3500 µm

Insitec delivers on-line, real-time laser diffraction analysis for powders, emulsions, sprays, and slurries.

Make workflows more efficient in fast-moving production environments.

Measurement range: 0.1–2500 µm (lens-dependent)

Zetasizer Advance offers sensitive, easy-to-use dynamic light scattering and zeta potential measurements for sub-micron and nanoparticle systems.

Predict agglomeration, control stability, optimize adhesion, and maximize washcoat shelf-life.

Automated image analysis instruments.

Morphologi 4 delivers automated image analysis of particle morphology. deliver detailed shape and structural insights from tens to hundreds of thousands of particles, enabling effective troubleshooting and optimization of dispersion, sphericity, and microstructure. In addition, **Morphologi 4-ID** identifies particle chemistry by Raman spectroscopy.

Density & powder rheology

Density and flow behaviour strongly influence catalyst processing, shaping, and handling. Gas pycnometry determines true (skeletal) density and is sensitive to change in composition. Envelope and bulk density can reveal porosity and elucidate packing behaviour.

True density measurement is provided by the **AccuPyc 1350**. This unit offers a captive lid, temperature control and a high quality touchscreen. Up to ten units can be connected across a plant enabling easy data viewing and the certainty of reproducing experimental methods between units.

The **GeoPyc 1365** can determine both envelope and bulk density. Used in conjunction with the AccuPyc it offers a fast and easy way to sample porosity using envelope desnity and to total pore volume with bulk density.

Process relevant testing is the key phrase for powder rheometry. A production process may experience issues with mixing, silo discharge, transport, humidity or temperature. The **Freeman FT4** offers a variety of test procedures to identify differences between materials and their behaviour at a particular stage of a process. The test is sensitive to all properties of the powder, size, shape, density and other properties such as residual moisture.

Selection guide

Technique and instrument mapping.

Application need	Primary technique	What it measures/ why it matters	Recommended instrument type	Associated norm
Verify metal loading (Pt, Pd, Ni, Co, etc.)	XRF	Elemental composition; loading accuracy	Zetium or Epsilon range	
Detect catalyst poisons (S, P, Cl, Na, V)	XRF	Trace impurities and contaminants	Zetium	
Check batch-to-batch formulation consistency	XRF	Elemental uniformity across batches	Zetium or Epsilon range	ASTM D7085
Confirm crystalline phases	XRD	Phase ID vs. references	Empyrean or Aeris	ASTM D4926 / ASTM 3906 / ASTM 3942
Monitor phase changes during heating/reaction	In situ / operando XRD	Structural evolution in real time	Empyrean	
Quantify crystallite size & strain	XRD (Rietveld)	Microstructure, sintering	Empyrean	
Determine oxidation state	XAS (XANES)	Valence state of active metals	Empyrean	
Identify local atomic coordination	XAS (EXAFS)	Bond distances, neighbours, disorder	Empyrean	
Measure surface area	Physisorption (BET)	Total accessible surface	3Flex / TriStar II / Gemini VII / ASAP	ASTM D3663 / ASTM D4222 / ISO 9277
Determine pore size / volume distribution	Mercury Porosimetry & Gas Adsorption	Micro-, meso-, macro-pore structure	AutoPore V (part 1) & physisorption (part 2)	ISO 15901 - 1 ISO 15901 - 2
Single point BET	Physisorption (BET)	Estimation of BET surface area	AutoChem III 2930 / ChemiSorb Auto / 3Flex. ICCS for in-situ analysis	D4567
Pore volume distribution	Mercury Intrusion Porosimetry	Pore volume distribution	AutoPore V	ASTM D4284
Evaluation of pore size distribution and porosity of solid materials by mercury porosimetry and gas adsorption	Mercury Intrusion Porosimetry	Evaluation of pore size distribution and porosity of solid materials by mercury porosimetry and gas adsorption	AutoPore V	ISO 15901 - 1
Measure through pore size	Porometry	Through pore size distribution	AccuPore	
Quantify active metal dispersion	Static Chemisorption	Number of active surface sites	3Flex / ASAP 2480 (where available)	ASTM D3908
Determine metal surface area	Static Chemisorption	Dispersion and metal crystallite size	3Flex / ASAP 2480 (where available)	ASTM D3908
Determine catalyst acidity	Static Chemisorption	Determine catalyst acidity	3Flex / ASAP 2480 (where available)	ASTM D4824
Study reduction / oxidation behavior	TPR/TPO/TPD	Temperature- dependent chemistry	AutoChem III 2930 / ChemiSorb Auto / 3Flex. ICCS for in-situ analysis	

Selection guide (continued)

Application need	Primary technique	What it measures/ why it matters	Recommended instrument type	Associated norm
Evaluate catalyst activation	TPR	Reduction profiles	AutoChem III 2930 / ChemiSorb Auto / 3Flex. ICCS for in-situ analysis	
Evaluate catalyst deactivation / coking	TPO	Quantify CO / CO_2 production	AutoChem III 2930 / ChemiSorb Auto / 3Flex. ICCS for in-situ analysis	
Evaluate catalyst chemistry / acidic / basic / redox	TPD & TPSR	Decomposition / desorption – NH_3 / CO_2 / amines / MeOH	AutoChem III 2930	
Evaluate heat of desorption (HOD)	TPD	Desorption profiles under differing ramp rates	AutoChem III 2930 / ChemiSorb Auto / 3Flex	
Characterize coke formation	TGA / Raman / DRIFTS / TPO	Decomposition & surface species	Morpholigi 4-ID / Chemisorption	
Measure mechanical strength (extrudates/ pellets)	Dilatometry / Mechanical testing	Strength, expansion, cracking behaviour	Dilatometer	
Analyze particle size of powders	Laser Diffraction	Size distribution	Mastersizer	ASTM D4464
Analyze nanoparticles and colloids	DLS	Hydrodynamic size	Zetasizer	
Evaluate slurry stability	DLS	Dispersion & flow properties	Zetasizer	
Determine particle shape and morphology	Automated imaging	Shape factors, agglomeration	Morphologi-4	
Identify surface intermediates	Raman / DRIFTS	Reaction pathways	Morpholigi 4-ID	
Monitor deactivation pathways	Raman / TGA / XRD	Coke, sintering, phase changes	Raman + TGA + XRD	
Full catalyst lifecycle workflow	Integrated multimodal approach	Structure–property–performance relationships	Combined XRD + XRF + sorption suite	
Catalyst performance	FR100 & FR200	Flexible options for gas and liquid catalysis at temperature and pressure	FR series reactor technology	
Process development	Pilot plant	Bespoke reactor systems to enable scale up	Pilot plant	
True density	Gas pycnometry	True density – raw materials to finished product – composition sensitive. Use with solids, liquids and slurries, eg. wash coat	AccuPyc 1350	ASTM D6761 / ISO 12154
Envelope & bulk density	Pycnometry	Determine envelope and bulk density. Use with AccuPyc to obtain % porosity	GeoPyc 1365	
Powder rheology	Rheology	Carry out process relevant measurements to understand needed powder characteristics	Freeman FT4	

Summary selection guide

Investigate	Interest	Solution	Instruments
Physical properties	Surface area	Gas porosimetry	3Flex, ASAP 2425, ASAP 2460, TriStar & Gemini
	Porosimetry	Gas porosimetry (0.35 nm - 400 nm) and mercury porosimetry (3.6 nm - 1,100 µm)	Above plus AutoPore
	Porometry	Capillary flow porometry (13 nm - 500 µm)	AccuPore
	Particle size	Laser diffraction (0.01 - 3,500 µm) and dynamic light scattering (0.3 nm - 15 µm)	Mastersizer and Zetasizer
	Particle shape	Image analysis	Morphologi 0.5 - 1,300 µm ESD
	Density	Gas pycnometry and volume displacement	AccuPyc and GeoPyc
Chemical properties	Reactivity and valence	Chemisorption	3Flex, AutoChem III 2930, ChemiSorb Auto & ICCS (in-situ)
	Elemental composition	X-ray fluorescence (XRF)	Zetium, Epsilon & Revontium
	Chemical composition	Mapping surface chemistry	Morphologi ID
	Colloidal stability	Zeta potential	ZetaSizer
Structure	Molecular structure	X-ray diffraction (XRD)	Empyrean & Aeris
	Oxidation state	X-ray absorption spectroscopy XAS (XANES)	Empyrean
Process	Powder processing	Powder rheology	FT4
	Reactor	Highly configurable bench top reactors	FR100 & FR200
	Pilot plant	Bespoke pilot plant	Pilot plant
	Particle size	On-line particle sizing (0.01 µm - 2.5 mm)	Insitec

Resources

Malvern Panalytical

Find the following resources on **www.malvernpanalytical.com/en/learn/knowledge-center**

- **Analysis of catalyst materials using laser diffraction particle size analysis**
- **Differential PDF for the structural characterization of supported catalysts**
- **Zetium - The analysis of total chloride in alumina-supported catalysts by WD XRF according to UOP 979**

Micromeritics

Find the following resources on **www.micromeritics.com/resources**

- **Acid Site Characterization of H^+ ZSM-5 (SiO_2/Al_2O_3:30/1): A Pulse Chemisorption and TPD Application for the AutoChem**
- **Acid Site Characterization of NH_4^+ ZSM-5 (SiO_2/ Al_2O_3:280/1): A Pulse Chemisorption and TPD Application for the AutoChem**
- **Ammonia TPD for Heat Sensitive Materials on the Autochem III**
- **An Introduction to Chemical Adsorption Analytical Techniques and Methods**
- **Characterization of Acid Sites Using Temperature-Programmed Desorption**
- **Effect of O_2 Traces in the Carrier Gas on Quantifying the Active Species in Catalysts**
- **Evaluating Catalyst Substrates with the GeoPyc® 1365**
- **Temperature Programmed Reduction Using the AutoChem**

About Malvern Panalytical

Together we are a powerful and highly complementary combination of market leading technologies. We are the toolmakers for the world's most innovative companies, academic institutions, and government laboratories.

More than 92,000 of our instruments are used every day in our customers' laboratories. Customers value us not only for the power of our analytical technologies, but also for the depth of our expertise. We are their partners in discovery. Customers see the difference when they use our instruments and feel the difference when they deal with our people.

Malvern Panalytical instruments analyze the chemical, physical and structural nature of materials, from proteins to polymers and semiconductors to minerals. Our leading technologies measure particle size, shape, concentration and zeta potential, biomolecular interactions and stability, elemental concentrations and crystallographic structure.

We have a global footprint with R&D and manufacturing sites in North America, Europe, and Asia. We are more than 2,500 employees in a customer-focused organization with sales and service offices in 20 countries, all committed to delivering expert and responsive customer support. We are committed to achieving Net Zero in our operations by 2030, and across our total value chain by 2040. We are part of Spectris plc, a publicly traded FTSE 250 company. Spectris combines precision with purpose, delivering progress for a more sustainable world. Precision is at the heart of what we do – our leading, high-tech instruments and software equip our customers to solve some of their greatest challenges to make the world cleaner, healthier and more productive.

Service & Support

Malvern Panalytical provides the global training, service and support you need to continuously drive your analytical processes at the highest level. We help you increase the return on your investment, and ensure that as your analytical requirements grow, we're there to support you.

Our worldwide team of specialists adds value to your business processes by ensuring applications expertise, rapid response, and maximum instrument uptime.

- Proactive local and remote support
- Full and flexible range of service agreements
- Compliance and validation support
- Onsite or classroom-based training courses
- e-Learning training courses and web seminars
- Digital services, including MyStore and My Customer Support Portal
- Sample analysis, method development, and applications consultancy

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