NETZSCH

Isothermal Battery Calorimetry IBC 284

Method, Instrumentation and Application

Leading Thermal Analysis

Illustration: Dean Armstrong / NREL

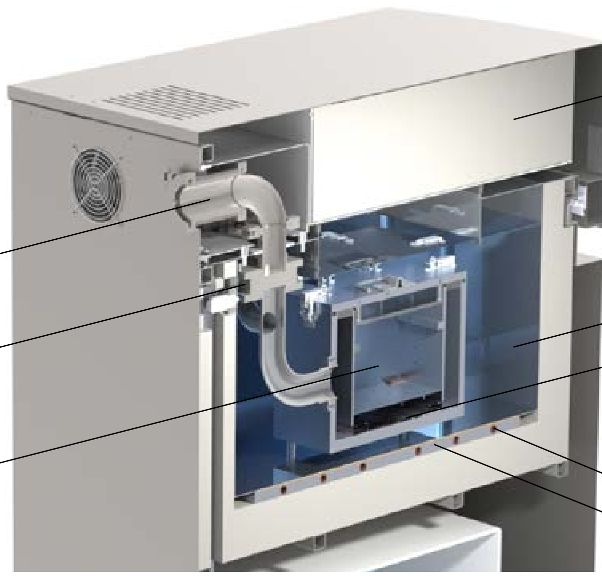
ISOTHERMAL CALORIMETRY

A Crucial Tool for Thermal Management of Battery Packs

The success of electric-driven vehicles (EDVs) relies on the lithium-ion battery technology. While the battery manufacturers strive to develop more compact and powerful battery packs for EVDs, thermal management continues to be a major challenge because temperature is critical to battery performance, life, and safety. Numerous high profile accidents in recent years have exemplified this challenge.

The IBC 284 is the testing equipment of choice when it comes to study high power and large battery packs for application in electric drive vehicles or airplanes. It was co-developed by the National Renewable Energy Laboratory (NREL, Golden, Colorado, USA), one of the leading research organizations in the development of analytical tools for designing optimized battery thermal management systems, and NETZSCH.

The information gained from IBC 284 enables engineers to identify and classify materials and configurations suitable for advanced battery thermal management systems already in the early development stage and thus to reduce time to market.



Cut-away of the IBC 284

Calorimetry is the science of measuring the heat of chemical reactions or physical changes of a specimen. Depending on the transition or reaction of interest, the heat may be generated (exothermal process), consumed (endothermal process) or just dissipated by the sample which is applied to a controlled temperature profile.

For measuring inhomogeneous samples such as entire EVD battery packs, isothermal calorimetry, i.e., calorimetry at a defined constant temperature, is ideal. The isothermal temperature regime additionally simplifies the kinetics within the results.

The IBC 284 consists of a large volume analysis chamber, submerged in an isothermal bath. In contrast to air cooling systems, liquid heat-transfer fluids feature a much better temperature stability than gaseous media. In the IBC 284, a glycol-water mixture is used to reach also sub-ambient temperatures. Heat-flux gauges embedded in the bottom of the analysis chamber detect the heat released by the battery sample.

For cycling experiments, a commercial battery tester can be employed to charge and discharge the battery pack.

IBC 284

R&D AWARD WINNER IN 2013

The IBC 284 was winning the renowned R&D 100 award in 2013. This award, also sometimes called "Oscar of Innovation", dignifies the most sophisticated high-tech products of each year.

Ease of Use

The IBC 284 is ergonomically designed for a single operator to quickly set up and run numerous testing scenarios. The liquid level is conveniently controlled for sample loading and unloading. Large gauge, low-resistance cabling is secured into the design for easy connection to an external battery cycler system.

Various Safety Measures:

Slight Overpressure in the Analysis Chamber

In order to avoid intrusion of the heat-transfer fluid into the analysis chamber, the chamber is slightly pressurized with nitrogen, air or argon (automated dedicated controller).

Burst Disk

In case of battery thermal runaway, the burst disk will rupture and relieve the pressure inside the test chamber to maintain safety and protect the analysis chamber from damage.

For Various Kinds of Batteries

The IBC 284 measures heat signatures of large format cells, but is also able to test smaller cylindrical, pouch and prismatic cells.

Reduced Time-to-Market

Calorimetric-driven development can dramatically shorten the R&D period.

Smart Concept for True Battery Heat Measurements*

Several design features, including an optimized heat-flux gauge location, routing the power cables through the isothermal bath and the attachment of the high-power connections to the test chamber, are introduced to eliminate heat losses.

* Patented instrument "Calorimeters for Testing Energy Storage Systems and Power Electronics Methods of Making the Same and Methods of Use"

Independent Determination of Charging and Discharging Efficiency

The IBC offers the possibility to characterize the efficiency of batteries over different temperature ranges and states of charge (SOCs) with high accuracy.

The IBC 284 is devised for accurate heat measurements, resulting in a better thermal management, improved performance, lifetime and safety of battery systems.

GROUNDBREAKING TECHNOLOGY

The IBC 284 is the isothermal battery calorimeter for large battery packs. It has several unique, innovative features that allow it to be very accurate even with large batteries. These features include:

- **Total Thermal Insulation through Submersion**

  The battery test chamber is completely submerged in an isothermal bath with very tight temperature control so that the ambient temperatures do not influence the heat-flux measurements.

- **High Sensitivity Detection**

  Heat-flux gauges can measure small quantities of heat energy flowing to/from the isothermal bath surrounding the analysis chamber.

- **Real World Temperature Range**

  The IBC 284 operates from -30°C to +60°C covering the battery-pack testing range for all climates in accordance with the United States Advanced Battery Consortium (USABC) guidelines.

- **Control Software for Turnkey Operation**

  The IBC 284's optimized control software can be pre-programmed to run a user defined temperature and stabilize before starting the charge or discharge test. Ergonomic design allows for fast test set-up and easy operation.

One Instrument for Various Battery Sizes

The size of the IBC 284's analysis chamber allows cells and modules of different sizes to be tested – from large vehicles batteries with a feed size of 12x8x6 inches (30x20x15 cm) to small 18650 cells which are placed centered at the bottom of the chamber.

Innovative Heat Retention

Batteries for hybride electric vehicles (HEV), plug-in-hybride electric vehicles (PHEV) and electric vehicles (EV) can produce currents over 300 amps; large copper conductors are therefore required to safely carry these currents. Since these high-thermal-conductivity copper cables are connected to battery terminals, they can conduct heat directly out of the calorimeter. This means (according to an NREL study) that up to 30% of the heat generated in the battery does not get measured by the heat-flux gauges. The IBC 284 is the only commercial calorimeter in the world that addresses this problem – it features heat-sinking busbars and cables routed though the isothermal bath.

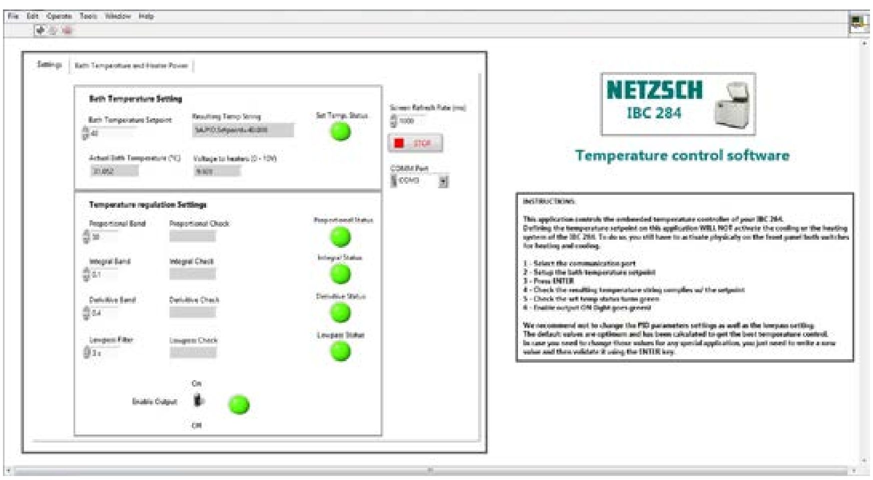
IBC 284

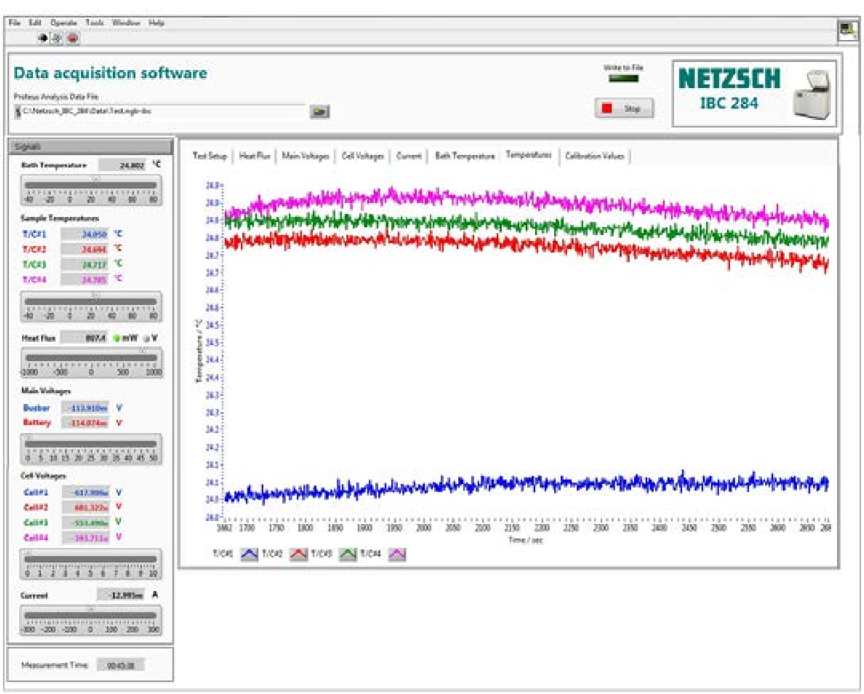
DATA YOU CAN TRUST

Technical Specifications of the Calorimeter	
Maximum battery size	12 x 8 x 6 (inches) 30 x 20 x 15 (cm)
Maximum power (heat measurement)	50 W
Sensitivity	30 mW
Temperature range	-30°C to 60°C
Baseline noise	5 mW
A/D	24 bit
Data acquistion rate	10 to 20 Hz
Heating/cooling	5°C/hr
Isothermal bath (temperature stability)	±0.01°C
Enthalpy accuracy	±2%
Third party cycler	Turn-key solution available
Specification typical cycler	Dependent Charge/discharge current: up to 300 A Current accuracy: 5 mA Voltage accuracy: 1 mV Charge/discharge volts: 50 V
Pressure accuracy	5% FS (0 to 10 psi transducer) (0 to 70 kPa)

Intelligent Software Solutions

The IBC measurement software, specifically tailored to large battery testing and the sophisticated and user-friendly NETZSCH *Proteus*® analysis software form a powerful set of tools. Running under the operation systems Windows™ 7 and Windows™ 8, this combination offers a wide range of essential routines. Amongst others, the following features can be found:





Measurement Part

- Easy set-up with online instruction
- All measured signals plotted in real time
- Easy access to calibration files

Analysis Part

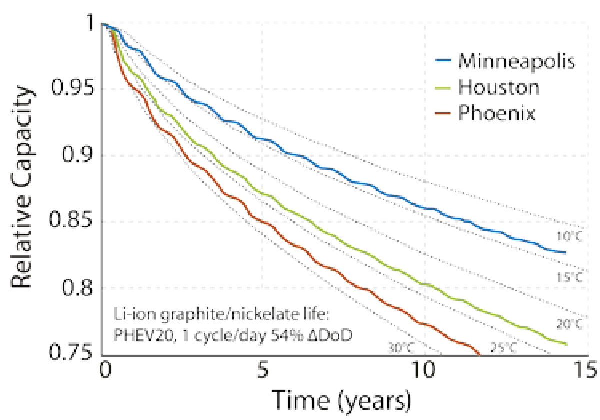
- Individual plot of multiple temperatures (based on the various thermocouples), voltages and currents
- Plot of the measured heat-flux signal
- Heat correction based on busbar isolation
- Enthalpy calculation
- Calculation of the electrical power (calculation based on the measured voltage and current)
- Integration of the electrical power to get the total power
- Calculation and integration of the heat power
- Calculating efficiency by comparing heat losses to electrical power
- Plotting efficiency as a function of current or temperature

The two screen shots show the user interfaces for temperature control and data acquisition.

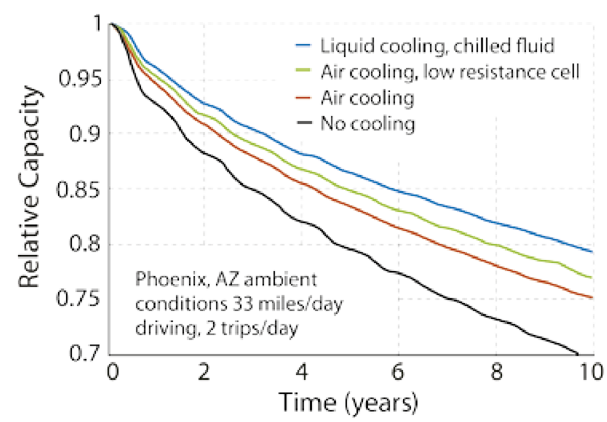
Many car manufacturers facing the Corporate Average Fuel Economy (CAFE) standards in the US (54.5 miles per gallon by 2025) or the mandatory CO_2 emission reductions targets for passenger cars (95 g/km by 2021) set by the European Union are looking at electric-drive strategies. Batteries that power these cars need to be affordable, high-performing, long-lasting, and operate at maximum efficiency in a wide range of driving conditions and climates.

But inadequate and inaccurate knowledge of batteries' thermal properties can negatively affect lifespan, safety and costs.

Influencing Factors for Battery Life Time



Geographic Impact on Battery Life (Data from NREL)



Thermal Design Impact on Battery Life (Data from NREL)

As illustrated in the figure below, a battery pack in a PHEV20* without cooling in a hot climate (like in Phoenix/Arizona) can last 7 years while the same battery could last almost 15 years in a cooler climate (like in Minneapolis/Minnesota), if a drop down of the relative capacity to approx. 82% is taken as a criterion.

An analog effect can be achieved by increasing the cooling efficiency.

The IBC 284's accurate measurement of batteries' thermal performance under various electrical loads and boundary conditions makes it possible for battery system engineers to design effective management systems.

* PHEV = plug-in hybrid electric vehicle

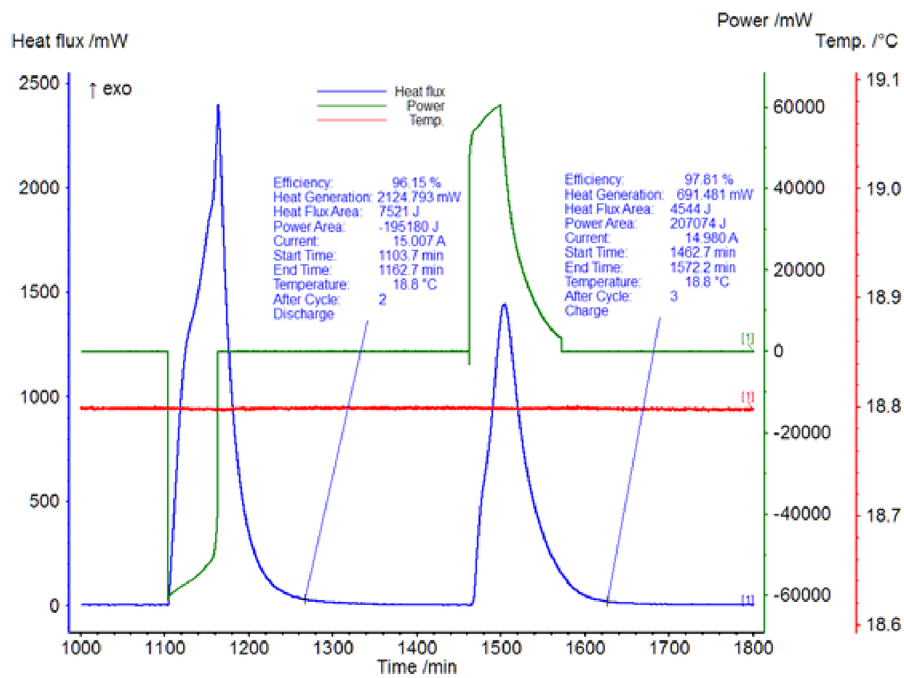
Heat Output of a Pouch Cell

The IBC is able to provide critical heat generation and efficiency data for a battery under charge/discharge conditions. In the past, battery manufacturers could only estimate the round-trip efficiency of a battery through electrical measurements. The IBC 284, however, measures the heat directly. Therefore, it becomes possible to determine the loss mechanisms and thus the battery efficiency for both charge and discharge currents independently.

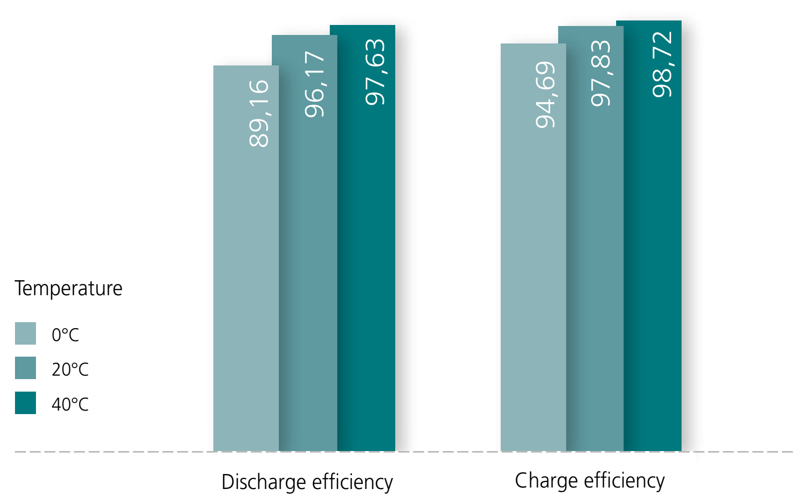
Here, a series of tests was conducted on a single pouch cell (15Ah) to measure the heat output at different operating temperatures. A standard CC/CV (constant current/constant voltage) protocol – from 2.5 V to 4.15 V at 1C** until the current dropped down to 750 mA – was used for all tests. A single example of a charge and discharge cycle, which was performed at 20°C, is shown in the left figure on the right.

When the battery is cycled at 40°C, the heat generated by the cell and the Joule heating represents 2.37% (= 100% - 97.63%) of the total energy supplied by the battery (discharge efficiency). At 0°C, it is 10.84% of the total energy. This proves that the IBC 284 is sensitive to measure low level differences at heat rate generation as well as peak heating which varies widely depending on whether the battery is tested at 0°C, 20°C or 40°C.
The right graph highlights the temperature-dependent behavior of the battery. In terms of efficiency, the difference between 0°C and 40°C is lower than what is measured during a discharge; the charge efficiency just increases from 94.69% at 0°C to 98.72% at 40°C.

** 1C refers to the discharge within 1 hour



Above: Examplary measurement of a pouch cell at 20°C; depicted are the heat-flux signal in blue, the power signal in green and the temperature of the isothermal bath in red.

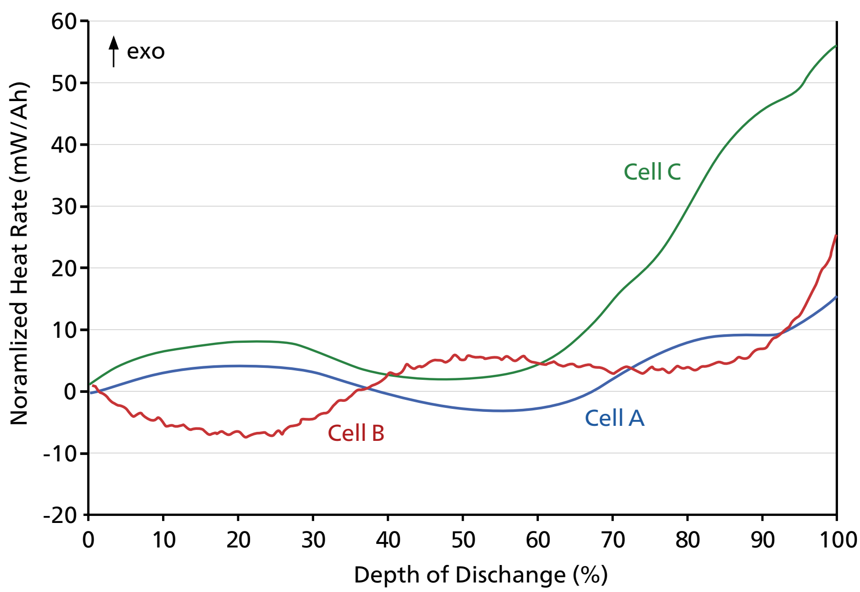


Temperature-dependence of charge/discharge efficiency

Entropic Cell Studies

During charging/discharging, heat in a cell is produced by both the resistance of the various cell components (Joule heating) and the entropic reactions which are the exothermic or endothermic reactions within the cell due to the transfer of ions and electrons. The IBC 284 will provide information about heat generation as a function of depth of discharge (DOD). This information can help understand cell performance.

These entropic studies are normally conducted at low charge rates, and low heat output, so high sensitivity is important. A low charge or discharge rate reduces the contribution of the non-reversible heat and reduces the heat gradient within the cell. In the example below, three fully charged cells, with varying chemistries, were discharged at constant current at a rate of C/10 (1 C refers to the discharge within 1 hour). Entropic studies identify regions of the discharge curve where cells are highly resistive – as an example, Cell C has very high impedance below a depth of discharge of 80%. Such studies can provide an understanding on how to improve efficiency and lifetime as a function of operating temperature.



Entropic Cell Studies – C/10 Constant Discharge of Three Different Cells at 30°C (Data from NREL)

Expertise in Service

All over the world, the name NETZSCH stands for comprehensive support and expert, reliable service, before and after sale. Our qualified personnel from the technical service and application departments are always available for consultation.

In special training programs tailored for you and your employees, you will learn to tap the full potential of your instrument. To maintain and protect your investment, you will be accompanied by our experienced service team over the entire life span of your instrument.

The NETZSCH applications laboratories are a proficient partner for nearly any Thermal Analysis issue. You will receive high-precision measurement results and valuable interpretations from us in the shortest possible time. This will enable you to precisely characterize new materials and components before actual installation, minimize risks of failure, and gain decisive advantages over your competitors. For production problems, we can work with you to analyze concerns and develop solutions.

- Installation and commissioning
- Training
- Hotline service
- Preventive maintenance
- Individual maintenance services
- Calibration service
- On-site repairs with emergency service for NETZSCH components
- PC supported diagnostics
- E-mail reporting
- Moving / exchange service
- Technical information service
- Spare parts assistance
- Accessories catalogue
- Software update service
- Application support
- Environmental instrument recycling

NETZSCH

Comprehensive Solution Provider for Battery Design and Testing

NETZSCH offers a broad variety of techniques for determining thermal properties such as heat capacity, thermal conductivity and thermal expansion. When combined with thermodynamic and kinetic information from calorimetry, these methods provide the means for designing thermal models for batteries. This in turn allows one to explore the many different aspects of battery research, such as material optimization, reliability, safety analysis and long-term stability.

Calorimetry

Adiabatic (ARC®)
Differential Scanning Calorimetry (DSC)
Isothermal
Constant Power

Thermal Analysis

DSC/TGA-FT-IR
DSC/TGA-Mass Spec
TMA, DMA, DSC, TGA, DEA

Thermophysical Properties

Thermal Expansion
Thermal Conductivity
Heat Capacity

Software

Kinetics
Thermal Modeling
Safety Analysis

Battery Safety and Research Instruments

Differential Scanning Calorimetry

Five different instruments
for testing

- Safety screening
- Melting of separators
- Cathode/anode stability

Simultaneous Thermal Analysis

Four different instruments
for testing

- Oxidation of anode
- Cathode decomposition analysis
- SEi (solid-electrolyte interface) decomposition

Multiple Mode Calorimetry

Modular instrument
for testing

- Thermal testing of coin cells
- Compatibility (cathode materials, electrolytes)
- Effect of SOC (stat of charge)

Adiabatic Calorimetry

Three different instruments
for testing

- Full cell
- PTC (positive thermal coefficient), CID (circuit interrupt device), vent design
- Thermal management data

Laser Flash Analysis

Three different instruments
for determination of

- Thermal diffusivity
- Thermal conductivity
- "Jelly-roll" thermal transport (jelly-roll = design principle of cylindrical recharge-able batteries)

Isothermal Battery Calorimetry

IBC 284

- Large batteries and packs
- Thermal management optimization
- Maximum performance safety and lifetime

The NETZSCH Group is a mid-sized, family-owned German company engaging in the manufacture of machinery and instrumentation with worldwide production, sales, and service branches.

The three Business Units – Analyzing & Testing, Grinding & Dispersing and Pumps & Systems – provide tailored solutions for highest-level needs. Over 3,400 employees at 210 sales and production centers in 35 countries across the globe guarantee that expert service is never far from our customers.

When it comes to Thermal Analysis, Calorimetry (adiabatic & reaction) and the determination of Thermophysical Properties, NETZSCH has it covered. Our 50 years of applications experience, broad state-of-the-art product line and comprehensive service offerings ensure that our solutions will not only meet your every requirement but also exceed your every expectation.

Leading Thermal Analysis

NETZSCH-Gerätebau GmbH
Wittelsbacherstraße 42
95100 Selb
Germany
Tel.: +49 9287 881-0
Fax: +49 9287 881 505
at@netzsch.com

NGB · Isothermal Battery Calorimetry · EN · 0217 · NWS · Technical specifications are subject to change.