IMEKO International Measurement Confederation

Technical Committee TC20 Measurements of Energy and Related Quantities

Book of Abstract

International Conference on Measurements of Energy – ICME 2023

4th to 6th of September 2023
PTB Braunschweig, Germany

more information

Schedule

Monday, 04.09.2023

11:00 – 13:00	Registration Desk
13:00 – 13:30	Welcome address
13:30 – 14:00	Talk 1: Metrology for energy transition – A cross-cutting challenge Speaker: Dr. Fabian Plag, Affiliation: PTB Braunschweig, Germany
14:00 – 14:30	Talk 2: Competence centre for photovoltaic metrology at PTB Speaker: Dr. Stefan Winter, Affiliation: PTB Braunschweig, Germany
14:30 – 15:00	Talk 3: Emerging hydrogen metrology – a use case for metrology organized within the CIPM mutual recognition arrangement Speaker: Dr. Olav Werhahn, Affiliation: BIPM – PTB, Germany
15:00 – 15:30	(30 mins) Extended discussions with Tea/Coffee Break
15:30 – 16:00	Talk 4: Recent developments in dynamic pressure metrology Speaker: Dr. Richard Högström, Affiliation: VTT MIKES – Finland
16:00 – 16:30	Talk 5: Multiphase chemical transformation Speaker: Dr. Nils Hansen, Affiliation: Sandia National Laboratories – USA
16:30 – 17:00	Talk 6: Doubly fed induction generator vs. full size converter in wind turbines – a metrological efficiency comparison on a test bench Speaker: Mr. Zihang Song, Affiliation: PTB Braunschweig, Germany
17:30 – 18:00	Walk back for Dinner
18:00 – 20:00	WELCOME DINNER
20:00	End of Day

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Schedule

Tuesday, 05.09.2023

09:00 – 09:30	Talk 7: Recent advances in diagnostics for combustion and energy research: from mass spectrometry to laser spectroscopy Speaker: Prof. Fei Qi, Affiliation: Shanghai Jiao Tong University – China
09:30 – 10:00	Talk 8: ML-Enabled sensing in the Mid-IR Speaker: Prof. Aamir Farooq, Affiliation: KAUST – Saudi Arabia
10:00 – 10:30	Talk 9: A well-tuned and fast uncooled pyroelectric IR and THz receiver Speaker: B.Eng. Tim Huylebrouck, Affiliation: Laser Components – Germany
10:30 – 11:00	(30 mins) Extended discussions with Tea/Coffee Break
11:00 – 11:30	Talk 10: Flow measurement and leakage detection of co2 under ccs conditions Speaker: Prof. Dr. Yong Yan, Affiliation: University of Kent – The UK
11:30 – 12:00	Talk 11: Measurement of temperature distribution in a biomass silo based on acoustic tomography Speaker: Ms. Ge Guo, Affiliation: NCEP University – China
12:00 – 13:00	Lunch
13:00 – 13:30	Talk 12 Speaker: Dr. Roy Hermanns, Affiliation: TU Eindhoven – The Netherlands
13:30 – 14:00	Talk 13: Iron combustion – From single particles to metal flames Speaker: Prof. Dr.-Ing. Christian Hasse, Affiliation: TU Darmstadt – Germany
14:00 – 14:30	Talk 14: Recyclable metal fuels as future zero-carbon energy carrier Speaker: Prof. Dr. Fabien Halter, Affiliation: Université d'Orléans – France
14:30 – 15:00	Talk 15: Microgravity experiments – A key measure in extracting ultra-slow flame speed metrics Speaker: Dr.-Ing. Joachim Beeckmann, Affiliation: RWTH Aachen – Germany
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15:30 – 16:00	Talk 16: Heading towards enhanced precision in laminar flame velocity derived from expanding spherical flames Speaker: Dr. Alaa Hamadi, Affiliation: ICARE Orléans – France
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20:00	End of Day

Schedule

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09:30 – 10:00	Talk 19: The Characteristics and formatting mechanism of ammonia-hydrogen combustion pollutants Speaker: Dr. Guangyu Dong, Affiliation: Tonji University – China
10:00 – 10:30	Talk 20: Ventilation efficiency measurement of novel three fluid operated hollow fiber membrane based liquid desiccant airconditioning system using co2 tracer – gas test Speaker: Mr. Tejes PKS, Affiliation: NIT Rourkela – India
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Metrology for energy transition – A cross-cutting challenge

Fabian Plag

Physikalisch-Technische Bundesanstalt (PTB), Braunschweig, Germany

The energy transition from a predominantly fossil-fueled to a carbon neutral, sustainable and emission free energy system is one of the key challenges of our society. In this context, the metrology community plays a vital role by providing robust metrological solutions that underpin technological advancements and facilitate their successful implementation in the market. After all, reliable measurements are the prerequisite for a safe, secure, reliable, and accessible energy supply. The Physikalisch-Technische Bundesanstalt (PTB), the metrology institute of Germany, has set up the Innovation Cluster Energy (IC-E) combining its scientific disciplines to address the metrological aspects of energy transition and to pool PTB's activities in the field of renewable energies.

The work of IC-E includes measurement and calibration capabilities in the fields of solar energy and wind power which - in part - are unique worldwide, metrology for energy transition and distribution, energy storage elements, and metrological solution for the rapidly increasing development of hydrogen technologies as well as the cross-cutting topic on energy efficiency. Together with partners from industry, PTB's scientists are also developing suitable measuring methods and standards in these fields of work. Beside single disciplines the focus is on the coupling of energy sectors, on the reliable and secure operation of the electricity grid, and on hydrogen and its derivatives as energy carrier.

This contribution aims to provide an overview of the Innovation Cluster Energy, its interaction to digital and environmental topics and its links to European metrology networks EMNs under EURAMET, the European association of national metrology institutes.

Competence centre for photovoltaic metrology at PTB

Stefan Winter*, Stefan Riechelmann, Ingo Kröger, Hendrik Sträter, Konstantin Ladner, Michael Schrempf, Frank Weinrich, Bettina Friedel

Physikalisch-Technische Bundesanstalt (PTB), Braunschweig, Germany

Photovoltaic energy is a main pillar of the energy transition. Hundreds of billions of Euro will be invested every year world-wide. Consequently, every percent of measurement uncertainty leads to a financial uncertainty of billions of euros. For this reason, a measurement infrastructure for the photovoltaic sector has been established at PTB, which makes it possible to determine the power of cells and modules with the world's smallest measurement uncertainty.

For the yield of solar modules, however, not only the performance under standard test conditions is important, but also the efficient behavior of the solar module under all irradiation and weather conditions that occur during the course of a year in the climate zone concerned. Therefore, the „Energy Rating" according to IEC 61853 also considers the solar module behavior at different temperatures, irradiances, sun angles and even the influence of the wind. For the quantitative determination of the corresponding solar module properties, measuring facilities have been set up, which are presented in an overview.

Emerging hydrogen metrology – a use case for metrology organized within the CIPM mutual recognition arrangement

Olav Werhahn*[1,2]

[1]*Physikalisch-Technische Bundesanstalt (PTB), Braunschweig, Germany
[2] Bureau International des Poids et Mesures (BIPM)

Metrology has been successful with a couple of well proven concepts. One of those is comparing results and data with other groups, originating from other instrumentation, or methodologies. The most renown framework to organize, perform and report comparisons for metrology is the CIPM Mutual Recognition Arrangement (CIPM MRA). Since almost a quarter of a century, this metrology framework provides one of the most fundamental backbones of international measurement community around the globe. Key actors in the framework of the CIPM MRA next to the participating laboratories (National Metrology Institutes, NMIs and Designated Institutes, DIs) are the regional metrology organizations (RMOs) and the BIPM (in its greater meaning, i.e., the global organization). Harmonization and overseeing of all activities are managed by the Joint Committee of the RMOs and the BIPM (JCRB). This presentation is to highlight the latest developments of the JCRB and the outcomes of the CIPM MRA. A perfect use case for this is seen in the emerging hydrogen metrology serving needs and challenges of the hydrogen economy to diversify the energy market. The BIPM's Key Comparison Database (KCDB) for this serves as a valuable foundation of data and metrological solutions for measurement tasks on hydrogen.

As the outcome of the CIPM MRA, calibration and measurement capabilities get published by NMIs and DIs in the KCDB, the so-called CMCs. Alongside, the KCDB provides data and reports on all key (KC) and supplementary (SC) comparisons undertaken in the various metrology areas. Focusing on the hydrogen topic, different metrology areas are challenged for different quantities to be measured, all serving measurement tasks related to hydrogen, e.g., temperature, pressure, volume, mass flow, amount fractions, and isotope ratios. The contribution will showcase that different solutions and capabilities to measurement tasks are provided by the KCDB-listed CMCs and KCs/SCs, even though, at the time of publishing, the hydrogen was not yet in focus of the measurement community. It is the JCRB and the CIPM MRA key actors, including the RMOs, AFRIMETS, APMP, COOMET, EURAMET, GULFMET, and SIM, who cares for fair-play, scientific rigour and transparency worldwide making these metrology data internationally accepted.

The contribution attempts combining the two aspects, international metrology and hydrogen as source for future energy diversification. This way, metrology solutions to hydrogen measurement tasks will be discussed and hydrogen measurement needs requested to the metrology community taken up.

Recent developments in dynamic pressure metrology

Richard Högström*[1], Jussi Hämäläinen[1], Teuvo Sillanpää[1], Sami Nyyssönen[1], Christophe Sarraf[2], Gavin Sutton[3], Susanne Quabis[4], Oliver Slanina[4], Robert Wynands[4], Gustav Jönsson[5], Sembian Sundarapandian[5], Yasin Durgut[6], Menne Schakel[7], Wouter Stiphout[7], Jan van Geel[7], Richard Koops[7], Gerard Nieuwenkamp[7], Alexander Fateev[8], Michael Liverts[9], Carel Adolfse[10], Anders Öster[11], Sari Saxholm[12], Juho Salminen[13], Markus Aspiala[14], Christian Sander[15], Antun Pejak[15]

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Dynamic pressure measurements are a key requirement for process control in many demanding applications, such as internal combustion engines and gas turbines in power plants, aircrafts, ships and cars, as well as manufacturing, ammunition and explosion safety testing. However, the current practice of calibrating pressure sensors under static conditions significantly limits the achievable measurement accuracy — errors of up to 10 % can occur when sensors are used at dynamically changing conditions. Improvements in accuracy and reliability of dynamic measurements will enable development of next generation technologies and products with improved quality, energy and material efficiency, and safety. For instance, better knowledge about the pressure inside a combustion engine is needed for improving engine performance, i.e. engine power and fuel consumption. Within the European metrology research project DynPT (Development of measurement and calibration techniques for dynamic pressures and temperatures; 2018 - 2021) improved measurement and calibration techniques for dynamic pressures up to 400 MPa were developed. The main objective of the project was to: (a) Develop new measurement standards and validated calibration procedures; (b) Study the effect of different influencing factors on the dynamic sensor response with the aim of defining the most appropriate calibration procedures and measurement uncertainties in industrial applications; (c) Develop and validate new sensors for measuring dynamic pressure in demanding industrial applications, such as inside an internal combustion engine. Measurement standards for dynamic pressures (shock tubes and drop-weight devices) were developed to provide SI traceable calibrations in a wide pressure and frequency range 0.1 – 400 MPa and 1 – 30 kHz, respectively. The target uncertainty of 1 % for dynamic pressure was achieved in the pressure and frequency range up to 5 MPa and 100 Hz. At higher pressures and frequencies, the uncertainties were in the order of 2 % and 5 %, respectively. Studies on the influence of process conditions show that the response of dynamic pressure sensors is strongly frequency dependent even at frequencies well below the nominal resonance frequency of the sensor. Also, temperature was found to influence the response. Moreover, a novel sensor for dynamic pressure measurements at harsh conditions was developed and validated in real engine environments. As an outcome of the project, a solid metrological basis for dynamic pressure measurements was established for the first time. Calibration services, guidelines and new measurement technologies have been made available to industry to facilitate a shift from static to dynamic methods.

Multiphase chemical transformation

Nils Hansen

Sandia National Laboratories, USA

Basic chemical insights are needed to support the transition to energy-efficient chemical transformations such as heterogenous catalytic oxidation and plasma-assisted processes. This presentation highlights the basic concepts of our mass spectrometry approaches to study the reaction networks in these complex environments and applications. Using this technique, unprecedentedly detailed chemical insights are generated as it allows for the simultaneous and sensitive detection of all intermediates and products of the reaction network without prior knowledge of their identity. In the first part of the talk, we will highlight the chemical insights into plasma-assisted chemical looping combustion of simple hydrocarbons by CuO/NiO using low-temperature plasmas in a heated fixed bed, coaxial, double dielectric barrier discharge (DBD) reactor. Through time-dependent species measurements by an electron-ionization molecular beam mass spectrometer, we obtained chemical insights through the quantitative detection of intermediate and product species at various temperature and plasma conditions. We observed considerable enhancement of fuel oxidation from the plasma discharge at lower temperatures. At more elevated temperatures. A period of carbon build-up was observed when using NiO as an oxygen carrier. The second part of the talk highlights new insights into catalytic oxidation conversion of methanol near atmospheric pressure using near-surface molecular-beam mass spectrometry. In addition to a variety of stable C1-C3 species, we detected methoxymethanol (CH3OCH2OH), a reactive C2 oxygenate that had been proposed to be a critical intermediate in methyl formate production. Methoxymethanol was observed above Pd, AuxPdy alloys, and oxide-supported Pd. We explored temperature and reactant feed ratio dependencies of methoxymethanol generation. The results suggest that future development of catalysts and microkinetic models for methanol oxidation should be augmented and constrained to accommodate the formation, desorption, adsorption, and surface reactions involving methoxymethanol.

Doubly fed induction generator vs. full size converter in wind turbines– a metrological efficiency comparison on a test bench

Zihang Song*[1], Paula Weidinger[1], Maximilian Zweifel[2], Kai Kuhman[3], Alexander Stock[4], Cédric Blaser[5]

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Wind energy is projected to be the primary contributor to the expansion of renewable energies, and improving efficiency is one of the major objectives in the development process of wind turbine drivetrains. A method for determining the efficiency of wind turbine drivetrains on nacelle system test benches (NTBs) in a traceable and comparable manner has been sought after. The EMPIR project 19ENG08 WindEFCY [1] successfully tackled this challenge by devising an efficiency determination method based on traceable mechanical and electrical power measurements.

In the preceding study [2], we established the efficiency of a 2.75 MW full size converter based wind turbine with full traceability at various operating points on the 4 MW NTB situated at the Center for Wind Power Drives (CWD) of RWTH Aachen University. To achieve this, specialized transfer standards for mechanical and electrical power measurement were installed as integral components of the NTB. The measured overall system efficiency demonstrated 89 % at rated torque and speed. For the entirety of the operating range, the relative expanded measurement uncertainty for the efficiency was calculated to be between 0.30 % and 0.72 %.

In this paper, the same wind turbine nacelle is switched from a full size converter (FSC) to Doubly Fed Induction Generator (DFIG) converter. In the new converter concept, the generator's stator windings are directly connected to the grid, while the rotor windings are controlled through the power converter. Since the rotor currents are only a third of the stator current, the power electronics can be downscaled, resulting in lower costs of the system.

To investigate the system efficiency using DFIG converter, the wind turbine is measured at various operating points, allowing efficiency to be determined and visualised over a wide operating range. Using in-situ calibrated torque sensor on the low speed shaft (LSS) and external calibrated torque sensor on the high speed shaft (HSS), as well as current and voltage transducers, measurement uncertainty for efficiency determination is calculated for each measurement points. The measurement results are showing a metrologically approved system efficiency of 93 % at rated torque and speed using the DFIG converter system, which indicates a significant efficiency improvement of over 4 % comparing to the previously measured full converter system.

[1] P. Weidinger et al., "Need for a traceable efficiency determination method of nacelles performed on test benches," Meas. Sensors, vol. 18, p. 100159, 2021, doi: 10.1016/j.measen.2021.100159.

[2] Z. Song et al., "Traceable efficiency determination of a 2.75 MW nacelle on a test bench," Forsch. im Ingenieurwes., vol. 87, no. March 2023, pp. 259–273, doi: 10.1007/s10010-023-00650-1.

Recent advances in diagnostics for combustion and energy research: from mass spectrometry to laser spectroscopy

Fei Qi*[1], Zhongyue Zhou[1], Mingming Gu[1], Liangliang Xu[1], Xi Xia[1], Yang Pan[2], Jiuzhong Yang[2], Long Zhao[2]

1*Shanghai Jiao Tong University, 2University of Science and Technology of China

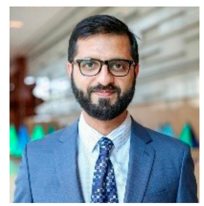
Reliable and predictable combustion model can help us to understand the combustion process deeply, and potentially help us to design higher-performance engines, increase combustion efficiency and reduce harmful emissions. However, the development of combustion model is badly relied on the advances of experimental and diagnostic methods. In this talk, basic experimental and diagnostic methods will be introduced. Some recent results will be presented with vacuum ultraviolet (VUV) photoionization mass spectrometry. Furthermore, the techniques can be applied in the detection of gas-phase products of heterogeneous reactions including catalysis reaction, biomass pyrolysis etc. And some recently built laser diagnostics systems at our laboratory will be introduced for application in swirling turbulent flame. Finally we will report on two facilities under construction that will be used for study of combustion and energy: Hefei Advanced Light Facility (HALF) and High-temperature High-pressure Optical Platform for Energy Research (H2OPER).

ML-Enabled sensing in the Mid-IR

Aamir Farooq

King Abdullah University of Science and Technology (KAUST), Saudi Arabia

Sensors based on laser absorption spectroscopy (LAS) have achieved widespread usage in research and practical applications due to their simple architecture, ease of implementation, and field deployment. Recent years have witnessed strong emphasis on the mid-IR wavelength region of the electromagnetic spectrum due to the presence of strong fundamental vibrational bands of many species of interest, availability of laser systems and the opportunities to do sensitive as well as selective detection. Machine learning based methods are helping overcome the challenges of spectral interference and noise and are enabling simpler systems. This talk will briefly describe some of the recent ML-enabled mid-IR sensing work carried out at KAUST. This includes the measurements of a family of aromatic molecules, BTEX, for environmental monitoring by exploiting cavity-enhanced absorption and deep-neural networks. This work was then extended to multi-species measurements in shock tube chemical kinetic studies. Machine-learning methods were exploited to overcome non-linear blending in liquid fuel samples and to do multi-species quantification from noisy spectroscopic data. Spectral augmentation strategies were then employed to account for unknown interference in real-world applications.



A well-tuned and fast uncooled pyroelectric IR and THz receiver

Shankar Baliga[1], Matthias Budden[2], Thomas Gebert[2],
Tim Huylebrouck*[3], Johannes Kunsch[3]

[1]Laser Components Detector Group, [2]Wired Sense GmbH, [3]Laser Components Germany GmbH

The pyroelectric receiver PR N°1 has been designed as a universal and well-tuned workhorse for metrology in the IR and THz. Design goal has been a WYSIWYG (what you see is what you get) functionality for straightforward data processing including scalability and repeatability based on a sufficient speed-performance combination. In our case, WYSIWYG does include the signal waveform, the signal linearity and the homogeneity over the active area. Consequently, the basic design did follow the "Bauhaus" principle of form follows function keeping in mind that:

- DLaTGS as "pyroelectric golden standard infrared material" cannot be used because of bad temperature behaviour, being hygroscopic and missing scalability.
- Instead, LiTaO3 has been chosen as basic material since it is well established in industrial sensing already with proven linearity.
- LiTaO3 allows to use Ni/Cr nanorod as black absorber manufactured by PVD process. The identical technology is being used for HIS infrared emitters. It is scalable, robust, homogenous, and fast.
- Thin material is needed to achieve the desired speed-performance combination.
- A micromachined chip can be manufactured by ion beam etching, i.e., a thin membrane is etched into the bulk material. This is a precise method, and it allows to place the bond wires at the frame leaving the active area untouched. The chip will be assembled by using 4 flexible posts for vibration dampening.
- The active element is operated in current mode which allows for a wide plateau where the signal is independent of frequency. A special amplifier needs to be developed for optimum trade-off between performance, speed, and minimum signal distortion.
- Current mode operation is more consistent at high temperatures.
- Eventually we found out, that a sweet spot is achieved by using a 2x2 mm2 active element with 6 µm membrane thickness and an amplifier bandwidth of 8 kHz.

The typical D* is 2 x 108 Jones at 1 kHz. This means that the performance of typical uncooled or TE-cooled longwave IR semiconductor devices is within reach (at a slower speed). Beyond appr. 12 µm there are no longer any TE cooled good semiconductor devices available and the PR N°1 takes over. Linearity has been proven to be within +/- 1 % over 4 decades. This has been measured by a double-slit superposition method and will be explained in detail at the presentation. The accuracy of the measurement setup is estimated to be within 0.5 %. Spot scanning of the receiver is under work. Results will be shown at the presentation.

A well-tuned universal linear and homogenous IR and THz receiver has been designed and built. We expect that it will boost the "People´s FTIR".

Flow measurement and leakage detection of co2 under ccs conditions

Yong Yan[1]*, Wenbiao Zhang[2]

[1]* University of Kent, UK, [2]North China Electric Power University

It is essential to measure the mass flow rate of CO2 for purposes of accounting, emissions trading and CCS system control. It is also important to detect CO2 leakage from transportation pipelines and storage facilities for safety and environmental purposes. However, significant changes in physical properties of CO2 (gas, liquid, two-phase or supercritical) mean that CO2 flows are complex in nature and difficult to measurement. Meanwhile, there are very few calibration facilities that can be used under CCS conditions. The presentation will introduce the challenges in this area of research and report the recent advance in developing measurement techniques for the mass flow metering and leakage detection of CO2 under CCS conditions. In particular, Coriolis flow metering techniques in conjunction with machine learning algorithms that are applied to achieve the mass flow metering of single-phase gas or liquid and gas/liquid two-phase flow under CCS conditions will be presented. Recent experimental work in applying acoustic, pressure and temperature transducers incorporating machine learning techniques for CO2 leakage detection will be reported. Experiences in the design and operation of a CO2 flow test platform under CCS conditions will also be presented.

Other projects in the area of energy measurement will also be introduced. These include the mass flow measurement of pulverized fuel (biomass/coal), on-line fuel particle sizing, flame stability monitoring, and structure health monitoring of wind turbines.

Measurement of temperature distribution in a biomass silo based on acoustic tomography

Ge Guo[1], Yong Yan*[2], Yonghui Hu[1], Wenbiao Zhang[1]

[1]North China Electric Power University, Beijing, China, [2*]University of Kent, Canterbury, UK

As a substitute for traditional fossil fuels, biomass is widely used to generate electricity and heat. Due to biological metabolic reactions, exothermic chemical reactions and heat-producing physical processes, self-heating and spontaneous combustion of biomass fuels are important issues related to the safe operation of biomass-fired power plants. In order to acquire timely and reliable temperature information about biomass fuels and hence minimize fire risks, it is essential to measure the temperature distribution of stored biomass in silos at power stations on an online continuous basis. However, existing instruments such as thermocouples and thermal imaging systems, are not suitable for measuring the internal temperature distribution of stored biomass. This paper presents a proposed measurement system, based on acoustic sensors coupled with tomographic reconstruction algorithms, to measure the temperature distribution of biomass stored in a silo. Meanwhile, low-frequency acoustic sensing and cross-correlation signal processing techniques are combined to measure the temperature and its distribution. An acoustic signal with a frequency of 200-1500 Hz is generated and transmitted through stored biomass. The flight time of swept-frequency sound waves between the two acoustic sensors is obtained through correlation signal processing. Tomographic reconstruction algorithms are applied to obtain biomass temperature and its distribution. The arrangement of acoustic sensors is shown in Fig. 1. Twelve acoustic sensors are installed on the outer wall of the silo. Wood pellets, which are widely used for power generation, are used as a test biomass fuel. Fig. 2 shows a typical temperature distribution in a wood pellet silo. The blue area represents wood pellets at ambient temperature. The high temperature is set to about 40°C higher than the ambient temperature. The reconstructed temperature distribution of biomass is given in Fig. 3. As can be seen, areas above the ambient temperature in the silo are clearly seen in the reconstructed image. These experimental results indicate that acoustic tomography is effective for the temperature distribution measurement of stored biomass within a relative error of ±8%.

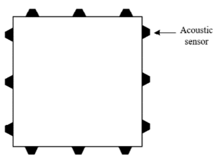


Fig. 1. Arrangement of acoustic sensors.

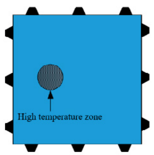


Fig. 2. Experimental setup.

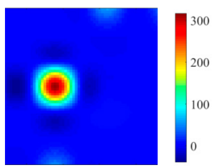


Fig. 3. Reconstructed temperature distribution of biomass

Keywords: Biomass, temperature distribution, acoustic tomography, image reconstruction

Dr. Roy Hermanns

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Confidential

Iron combustion – From single particles to metal flames

Daniel Braig[1], Johannes Mich[1], Bich-Diep Nguyen[1], Arne Scholtissek[1], Christian Hasse[1]*

[1]*Simulation of reactive Thermo-Fluid Systems, Technische Universität Darmstadt

The transformation of energy systems to achieve climate neutrality is one of the most pressing challenges of our time. In that context, metal fuels are emerging as a zero-carbon, high-energy density replacement for fossil fuels due to their availability and recyclability using renewable energy. Iron in particular is a promising option for a carbon-free cycle. Iron is non-toxic, safe to transport, easy to store, abundant, and in principle can be recycled an unlimited number of times.

In this presentation, iron as a metal fuel is first introduced as a recyclable chemical energy carrier for a carbon-free circular economy. During the reduction of iron oxides, energy from renewable sources such as wind and solar is stored. This energy is released again through oxidation and can be used as high-temperature process heat or for the generation of electricity.

This is followed by selected experimental and numerical results on the combustion physics of iron. First, the oxidation of single iron particles is presented, and the different phases of ignition and combustion are discussed with a special focus on the coupling of gas phase transport with the condensed phase kinetics. Next, canonical polydisperse iron-air flames, from which typical combustion characteristics such as the flame speed can be deduced, are studied. Going towards multidimensional flames, experimental and numerical results for a laminar self-sustained Bunsen-type jet flames are presented. The reaction zone structure and the reaction front speed are analyzed. The need for well-controlled and well-characterized experimental conditions to reduce uncertainties is demonstrated by comparison to simulation results. Finally, results for turbulent iron-air flames are presented.

Recyclable metal fuels as future zero-carbon energy carrier

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What if small metal particles were the future of energy? The possibility to use metal powder to store energy from intermittent renewable energy sources arises naturally as a close to zero GHG emission well-to-wheel specific reduction process can be performed from the oxidized metal particulates using concentrated solar energy. Micron-sized metal powders are easily transportable and have a practically unlimited shelf life when protected from humidity in hermetically-sealed containers. Combustion of these metal particles releases a large amount of energy and has the advantage of not emitting carbon dioxide. These particles, burning in air or other oxidizers, produce metal oxides which can then be regenerated using solar energy. This cycle energy production / recycling can make it possible to store energy produced with renewable energy in a secure and sustainable way, so that it can be used where and when it is needed. The proposed talk describes the work undergone on this original and promising concept. It is part of a disruptive technology to solve the problem of global warming in the long term.

Metal particles are likely to be used as a steady power source such as industrial burners. It appears that the durable stabilization of this type of flame requires a good control of the suspension of the particles. When burning aluminum, a very large part (>50%) of the energy is radiated from the reaction zone to the surrounding medium. This property, which results from the very high temperatures involved, will directly determine the heat recovery unit to be used. The oxides produced are heavier and bulkier than the initial particles, which may complicate their post-combustion storage. Their filtration remains quite easy, despite their nanometric size, due to their strong propensity to agglomerate. Almost complete filtration is achievable with conventional filtration systems. The formation of nitrogen oxides is favoured by high temperatures and an excess of oxygen. One solution to limit their concentration at the exhaust is to work close to stoichiometry.

Microgravity experiments – A key measure in extracting ultra-slow flame speed metrics

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RWTH-Aachen, Germany

Modern refrigerant design faces challenges in simultaneously improving efficiency, reducing global warming potential (GWP), and ensuring safe handling in practical applications. Commonly used hydrofluorocarbon (HFC) refrigerants have unsaturated molecules or fewer fluorine atoms, which are replaced by hydrogen, reducing their atmospheric lifetime due to their increased reactivity with oxygen. As a result, they are mildly flammable. The laminar flame speed SL,u determines their hazardous fire potential. Refrigerants with a low flame speed are less dangerous, but measuring slow flame propagation is challenging due to the influence of gravity and radiation on combustion. The combustion behaviour is comparable to conventional fuels burning under ultra-lean/rich or highly diluted conditions. Experiments must be conducted under microgravity conditions to isolate the effect of radiation from gravity. Recent achievements in the methodology of flame speed acquisition under microgravity conditions are presented. Experimental data were obtained during parabolic flight campaigns on the Airbus Zero-G, Bordeaux, France, and in the drop tower at the ZARM, Bremen, Germany. The impact of radiation is discussed, and recommendations for accurate flame speed measurements are suggested.

Heading towards enhanced precision in laminar flame velocity derived from expanding spherical flames

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Laminar flame speed refers to the propagation rate of the normal flame front relative to the unburned mixture. This parameter is of great importance in the study of combustion processes due to its wide-ranging applications across various fields. It plays a pivotal role in optimizing combustion efficiency and performance in engines and turbines, leading to reduced fuel consumption and enhanced energy efficiency. Additionally, its impact on combustion timing plays a vital role in curbing the formation of pollutants like nitrogen oxides and particulate matter, fostering cleaner and more environmentally friendly combustion processes. Its significance extends to safety, as understanding how quickly flames can propagate is essential for designing secure industrial systems, preventing undesirable phenomena like engine knock or detonation, and ensuring the durability of combustion systems. Hence, it is a fundamental parameter in combustion modeling that aids researchers in predicting and analyzing combustion behaviors under diverse conditions, and a critical factor in alternative fuel development that guides the selection and optimization of fuels for various applications. Consequently, it is crucial to have accurate laminar flame speed measurements. Nonetheless, various factors influence the precision of laminar flame speed, leading to considerable discrepancies in data within the literature. One of these factors pertains to the influence of the extrapolated flame radius domain on the derived laminar flame speed. A current study on oxygen-enriched ammonia demonstrates that larger domains negate this domain-related effect. The second aspect involves radiative losses. The intensity and spectral distribution of flame radiation are closely tied to factors such as flame dimensions, shape, mixture composition as well as local pressure and temperature. Notably, there is a lack of documented investigations into experimentally determined heat losses. This is where the Fast Absolute Infra-Red Sensor (FAIRS), developed and provisionally tested by Idir et al. [1], becomes relevant. Radiative heat losses have been quantified using a blend of hydrogen and methane, resulting in an estimated loss fraction of 1% attributed to radiation.

[1]Idir M, Rayaleh AM, De Sousa Meneses D, Semmar N, Chaumeix N. Absolute and real time experimental radiative loss measurements of spherical expanding free flames: FAIRS (Fast Absolute InfraRed Sensor)-An innovative technique. Rev Sci Instrum 2022;93:095103. https://doi.org/10.1063/5.0101519.

Standardisation of hydrogen fuel sampling for heavy-duty hydrogen transport – need for metrology

Oliver Büker

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Hydrogen can make a significant contribution to reducing emissions from the transport sector as it is particularly well suited as a fuel for long-haul heavy-duty vehicles. The uptake of hydrogen for heavy-duty transport requires further standardisation to support Europe's green energy future. Sampling systems and methods have already been developed for use at hydrogen refuelling stations for light-duty vehicles, however there is a lack of technical evidence for heavy-duty vehicles.

With the growing interest in the use of hydrogen and fuel cells in medium and heavy duty applications, the need for dedicated standards for these applications has increased. Currently, the number of hydrogen-powered buses, trucks and trains in Europe is around 500 units, but this is expected to grow at a very high rate. At least 60,000 hydrogen-powered trucks are expected to be in operation by 2030, requiring a large infrastructure of truck-friendly hydrogen refuelling stations.

Hydrogen-powered vehicles require extremely pure hydrogen, as some contaminants, even at very low levels, can reduce the performance of the fuel cell. Previous metrology projects have paved the way for the development of the European quality infrastructure for hydrogen conformity assessment. However, the reliability of a measurement is inextricably linked to the representativeness and reliability of the sampling itself. Poor sampling can lead to a fleet of HD vehicles being damaged. Furthermore, standardisation is required as the heavy-duty hydrogen refuelling station network will be shared between operators. Also, sampling practices should not be a source of quality variation within the emerging network.

An overview of the EURAMET European Partnership on Metrology project 22NMR03 "Metrology for standardisation of hydrogen fuel sampling for heavy duty hydrogen transport" (MetHyTrucks), which started in June 2023, is presented. The project aims to provide the necessary evidence for the standardisation of hydrogen fuel sampling for heavy-duty applications. This will include the development of dedicated contaminant sampling systems for both gaseous species and particulate matter, methodologies for the validation of sampling methods, guidelines for the evaluation of sampling representativeness, uncertainty budgets, safety considerations and venting protocols.

Acceptance of hydrogen fuel will only be achieved by minimising operational problems, which in turn is achieved through confidence and assurance that the required quality will be maintained. As acceptance of hydrogen-powered vehicles increases, these vehicles will increasingly be seen as normal road vehicles rather than prototypes or small fleets. Social acceptance of hydrogen as a fuel is essential for the energy transition towards a greener society.

Sustainable aviation fuels: From chemical compositions to particle exhaust gas

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Reducing the man-made carbon footprint is a worldwide challenge and one uniting global goal in our modern society. Sustainable aviation fuels (SAFs) are on the brink on replacing fossil fuels in the years to come. SAFs are produced from renewable feedstocks that have to follow strong environmental, social, and economic (circular) criteria. A strict ecological balance by avoiding depletion of natural resources and by not contributing to climate change is essential in the strategy to work. Based on the feedstocks used (bio-based, waste-based, or Power-2-X processes) and based also on the production synthesis processes, SAFs' composition can be close to a chemical copy of conventional crude-oil based Jet A-1/Jet A or hydrocarbons that are not found in conventional jet fuel. Understanding the impact of the chemical composition or properties, assessing and optimizing fuels, while taken constraints such as compatibility, and most of all in aviation safety, regulated by ASTM approvals into account, is the main scientific goal of our technical fuel assessment strategies.

From a chemical point of view, the final composition can differ in its total number of species, in its distribution of species within the kerosene cut, and/or in the species' chemical structures (e.g. different isomers) with respect to Jet A-1/Jet A. Utilizing such fuels in commercial aviation started first with the development of a robust approval process. The assessment of SAF candidates is not based on their chemical composition but rather on their properties and their performance with respect to physical and chemical sub-processes, which are key to the overall safety.

Understanding the impact of fuels on safe operation and handling, then on engine performance and emissions, and ultimately the environmental impact and climate forcing of aviation is key of the presented research. It is important to investigate and fully comprehend the effect of fuel composition on its physical and chemical properties and further on the sub-processes occurring in the combustion system. An overview is given on the chemical analytics, the experiments, the diagnostics and modeling methods, as well as real system in real world measurement campaigns, which enabled us to analyze these effects. Finally, the knowledge regarding these effects become the building blocks for proper fuel design.

The Characteristics and formatting mechanism of ammonia-hydrogen combustion pollutants

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Hydrogen can make a significant contribution to reducing emissions from the transport sector as it is particularly well suited as a fuel for long-haul heavy-duty vehicles. The uptake of hydrogen for heavy-duty transport requires further standardisation to support Europe's green energy future. Sampling systems and methods have already been developed for use at hydrogen refuelling stations for light-duty vehicles, however there is a lack of technical evidence for heavy-duty vehicles.

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Ventilation efficiency measurement of novel three fluid operated hollow fiber membrane based liquid desiccant airconditioning system using co2 tracer – gas test

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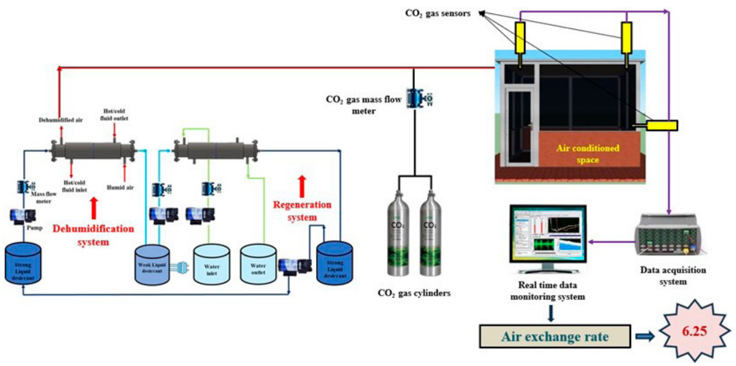
The demand for energy-efficient and sustainable air conditioning systems has led to the development of liquid desiccant dehumidification systems, which offer numerous advantages over conventional cooling technologies. In order to optimize the performance of these systems, it is crucial to accurately measure and evaluate the ventilation efficiency of the system. This study presents a novel approach to assess the ventilation efficiency in a novel three-fluid operated hollow fiber membrane-based liquid desiccant dehumidification system (TFLD) using CO2 tracer gas test. The liquid desiccant used is Lithium chloride (LiCl) and the hydrophobic membrane contactors are made of Polyvinylidene fluoride (PVDF). The experiment involves injecting a controlled constant amount of 4200 ppm CO2 gas into the varying dehumidified air stream of 0.25 kg/s to 0.51 kg/s, relative humidity (RH) and temperature of dehumidified air from 20% to 30% and 20 ˚C to 25 ˚C into a closed room. The measurements are carried out under different operating conditions to evaluate the system performance by monitoring its concentration at different locations by strategically placed sensors to capture the CO2 concentration levels every 10 seconds. The air exchange rate is considered as a performance parameter. Further, from the results it is observed that the maximum air exchange rate is obtained to be 6.25 and CO2 concentration is reduced to 950 ppm at 0.51kg/s airflow rate, 20% RH, and 21˚C. Hence, The CO2 tracer gas test proved to be a reliable and cost-effective method for evaluating ventilation efficiency in a hollow fiber membrane-based liquid desiccant dehumidification system. Furthermore, the findings of this study contribute to the overall understanding of system dynamics and support the development of more efficient and sustainable air conditioning technologies. The proposed methodology can serve as a valuable tool for system designers, engineers, and researchers involved in the development and optimization of liquid desiccant-based air conditioning systems.



A new experimental and numerical simulation method for measuring ash slag fluidity using VOF based on OpenFOAM

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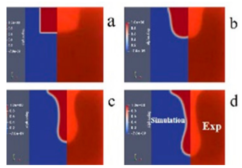
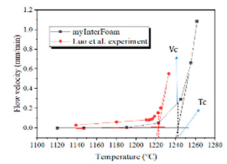
Coal demand in China is 3.9 billion tonnes per year, which is 540 million tonnes higher than in 2016. Meanwhile, slagging coal is abundant in China, which is a serious test for coal-fired boilers in terms of slagging on the heat exchange surface. Liquid slag boilers are particularly suitable for slagging coal with a strong burning force, high rates of slag removal, and minimal particulate matter in the flue gas. However, the ability to discharge the slag produced by the fuel after combustion is a decisive element in ensuring the secure functioning of the liquid-slagging boiler. Therefore, the measurement of ash fluidity is of great importance for China's energy security. The group uses an inverted flow method to characterize the flow of ash, which is cheaper than a high-temperature viscometer and gives more meaningful engineering results. A new visual image measurement method for the flow characteristics of ash slag has been developed, combining the flow velocity, throat width, characteristic flow temperature and other parameters of the ash slag sample to analyze the flow characteristics of the sample comprehensively. Also, a numerical computational model of heated ash flow is proposed using the Volume of Fluid (VOF) method based on OpenFOAM. The established numerical model can accurately calculate the critical flow temperature (Tc) and critical flow velocity (Vc) of ash slag with the error of 1.5% and 19% from the experiment, respectively. Forty-five types of ash slag with widely varied properties in China were calculated based on the established model. Results show that high levels (>30%) of Fe2O3 and CaO improve the flowability of the ash slag, and low levels of Al2O3 (10%) also contribute to the flowability of the ash slag. Tc and Vc of the ash were distributed in the range of 1150~1400°C and 0.1~1.0 mm/min, respectively. Tc and Vc change in opposite trends with the component content increases, indicating that a higher Tc corresponds to a lower Vc and fluidity reduction. Mathematical models for calculating the Tc and Vc of ash were obtained based on non-linear multiple regression and correlation coefficient, and prediction accuracy was within 10% and 30% for Tc and Vc, respectively. The proposed numerical simulation method and prediction model can provide an accurate reference for a wide range of ash fluidity.



Simulation and experimental results of ash inversion flow



Comparison of Luo et al. experimental and simulation results in Tc and Vc

A Project to investigate the effect of flexumer operation on the safety and reliability of second-life battery storage

Maedeh Askarzadehardestani*, Stefan Essmann

Physikalisch-Technische Bundesanstalt National Metrology Institute, Working Group: Renewable Energy Carriers and Storage

Flexumer operation refers to a flexible and dynamic cycling pattern used for testing and operating battery systems. It involves varying the charge and discharge rates, as well as the rest periods, in a more frequent and rapid manner compared to traditional cycling patterns.

The term „Flexumer“ is a combination of „Flexible“ and „Consumer,“ highlighting the dynamic and user-dependent nature of the operation. Flexumer operation allows for a more realistic simulation of battery usage in real-world applications. It captures the dynamic and variable nature of energy demand and supply, providing insights into how batteries perform under practical conditions.

The main focus of the joint project is to ensure that Flexumer systems can provide reliable instantaneous reserve, considering the impact on power electronics and batteries, as well as their longevity and dependability. Sub-project, „safety of battery storage,“ concentrates on addressing the safety concerns associated with using second-life batteries. This aspect is crucial for gaining acceptance of storage systems and ensuring safe operation throughout their extended service life.

The integrity of the entire battery storage system can be compromised by individual defective cells. Hence, it is essential to evaluate the condition of used cells before incorporating them into a second-life storage system. The sub-project aims to develop a method for assessing the condition of already-aged modules to determine their suitability for reuse. Another aspect considered in battery storage safety is aging. Over a significant number of cycles, the capacity of cells reduces, and the likelihood of errors increases.

The specific effects of using battery storage in a Flexumer setup are still unknown. Therefore, this sub-project examines the aging behaviour of batteries under these unique conditions to better understand their performance and reliability with the use of EIS (Electrochemical Impedance Spectroscopy), also an equivalent circuit diagram of the „battery“ system is helpful for the evaluation of EIS measurements. Depending on the question or area of application, the equivalent circuit diagram must be chosen differently. However, it is still unclear how individual defective cells in a module affect the optimal equivalent circuit.

1. Designing a second-life battery storage system suitable for Flexumer operation.
2. Developing and implementing a method to analyze the health and safety status of used batteries intended for second-life storage.
3. Conducting cycling tests on cells using realistic Flexumer and studying how these conditions affect battery aging.
4. Investigating the consequences of individual cell overloading caused by overcharging and deep discharging and analyzing their impact on battery modules using corresponding equivalent circuit diagrams.
5. Evaluating how the safety requirements influence the profitability of second-life storage systems.

Downhole measurement of gas-liquid carbon dioxide flowrate based on Venturi tube

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With the rapid development of CO2-EOR technology, an increasing number of offshore oil fields have embraced it to improve oil recovery. Simultaneously, injecting CO2 into wells has become a critical step in the CCUS process as well as an effective measure to combat global warming [1]. The advancement of this technology contributes to the enrichment of traditional offshore oil field injection technology, reducing interface tension and viscosity, resolving issues related to injection difficulty and poor effect in the development of low permeability and water-sensitive oil reservoirs, and boosting oil displacement efficiency [2]. However, due to limited installation area and complex CO2 phase transition, effective CO2 flow rate measurement remains a tough problem to solve [3]. Venturi has been widely utilized in single phase and multiphase flow measurement as a throttle flowmeter with low pressure loss and great durability [4]. However, the usage of Venturi in CO2 flow measurement is rarely reported. Other flowmeters such as ultrasonic, orifice plate and turbine have certain drawbacks. CO2 has an attenuating impact on ultrasonic signals. Additionally, CO2 may undergo phase transition as ambient pressure and temperature change, causing dramatic fluctuations in CO2 density and the required frequency range of ultrasonic transducer. Orifice flowmeters exhibit high pressure loss and energy consumption, while turbine flowmeters are prone to damaged and require frequent calibration [5]. In this study, Venturi was chosen as the key measurement element. Given the restricted space in downhole and wide gas injection flow range, the optimal Venturi diameter was determined to be 15 mm, which minimizes sensor size while maximizing differential pressure. The upstream, throat, and downstream pressure of Venturi were measured using three static pressure sensors with similar characteristics. The experiment was carried out using the CO2 gas-liquid two-phase flow rig at North China Electric Power University, under pressure of 5.2~5.5 MPa and temperature of 18~20°C. The gas flow range is 175.17~299.01 kg/h, and the liquid flow range is 87.18~102.95 kg/h. A calculating model was built based on the measurement data. The error bands of gas and liquid flowrates were -3.0~10.9 % and -24.0~24.5 % respectively. The results suggest that the optimized Venturi design offers certain forecasting ability in measuring gas-liquid CO2 flowrate.

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Mass Flow measurement of gas-liquid two-phase co2 under low liquid loading conditions through data-driven modelling

Qin Wang*[1], Wenbiao Zhang[1], Yong Yan[2]

[1]*North China Electric Power University, Beijing, China, 2University of Kent, Canterbury, UK

Carbon capture and storage (CCS) is a key technology to mitigate climate change and reduce CO2 emissions from the power and industrial sectors. In the CCS transportation chain, accurate measurement of CO2 mass flow in pipelines is crucial for financial accounting purpose and potential leakage detection. This paper presents data-driven models combined with Coriolis flowmeters to measure gas-liquid two-phase CO2 flow under low liquid loading conditions. Two data-driven models, including least squares support vector machine (LSSVM) and Gaussian process regression (GPR) are established through training with the experimental data for the measurement of CO2 mass flow and the prediction of CO2 gas volume fraction (GVF), respectively. Experiments were conducted on a CO2 gas-liquid two-phase flow rig on a horizontal pipeline for fluid temperature of 18-20 °C and pressure of 5.5-5.8 MPa. The liquid mass flow rate ranges from 60 kg/h to 600 kg/h and the gas mass flow rate is between 180 kg/h and 300 kg/h. A set of variables containing apparent mass flow rate, fluid temperature and apparent density are used as inputs to the models for CO2 mass flow measurement, while the prediction of GVF takes apparent mass flow rate and apparent density as inputs. Performance comparisons between the LSSVM and GPR models are conducted. When the test data is within the range of the training dataset, there is no significant difference in accuracy between the LSSVM and GPR models. The relative errors of CO2 mass flow rate and GVF predicted by the two models are within ±2.5% and ±1%, respectively. However, for the test data beyond the range of the training dataset, the performance of the GPR model is significantly better than that of the LSSVM model. The relative error of the GPR model is within ±1.5% for CO2 mass flow rate measurement and between −5% and 0% for GVF prediction, respectively. The results indicate that Coriolis flowmeters incorporating the GPR model has better generalization capability.

Quantitative measurement of burner flame stability through digital image processing

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Measurement of burner flame stability in a range of industrial sectors is desirable to improve the performance of furnaces, boilers and engines, ensuring the safety of operators and combustion systems and meeting the increasingly stringent standards on energy saving and pollutant emissions. However, existing methods for flame monitoring in industry measure only the brightness or temperature and detect the presence or absence of a burner flame. Algorithms for flame stability measurement are still limited. In order to quantitatively measure flame stability under a wide range of combustion conditions, a novel method based on digital image processing is developed. Fig. 1 shows a block diagram of the flame stability measurement method. The term 'flame stability' is defined as the degree of fluctuation of a flame due to all physical and chemical changes in the flame characteristics during combustion. A range of physical parameters of the flame, including geometric, luminous, and thermodynamic parameters, which provide instantaneous information on certain aspects of the combustion process, can be determined by processing flame images using digital image processing algorithms. The variability of different flame parameters reflects the degree of fluctuation of the flame from different perspectives. A flame stability index is quantified by combining the variability of all the available flame parameters for a given flame. The larger the stability index, the less stable the flame is. The flame stability index is then converted into a flame stability indicator ranging from 0 to 10 to represent one of five flame states, i.e., stable, relatively stable, unstable, extremely unstable, and extinguished. Experimental tests were undertaken firstly with LED and halogen bulbs as idealized ultra-stable flames and then on methane, biomass, and pulverized coal fired combustion test rigs to assess the effectiveness of the developed method. Fig. 2 demonstrates that the stability of the LED and halogen bulbs is quantitatively measured by the stability index. Fig. 3 illustrates the variations of the stability of a full-scale pulverized coal flame during a "turning off" routine.

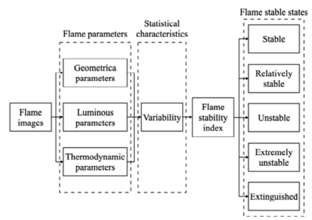

Fig. 1. Block diagram of the measurement method.

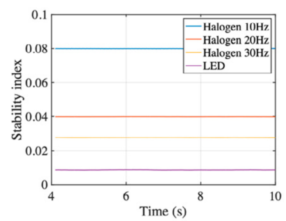

Fig. 2. Stability of LED and halogen bulbs.

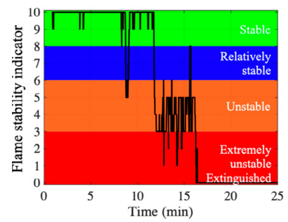

Fig. 3. Stability of a pulverized coal flame during a "turning off" routine.

Keywords: flame stability, flame monitoring, digital image processing, statistical analysis.

An enhanced system for the measurement of dc energy using adaptive signal conditioning blocks

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Renewable generation systems based on wind and solar energy presume direct current (dc) generation, storage of the generated energy (in order to compensate for fluctuation or interruptions) and regulation of the output voltage or conversion to alternative current. Direct current (dc) energy measurement for renewable generation systems is necessary in order to assess the amount of generated and stored energy and in order to monitor the state of the system. High resolution and precise monitoring of the fluctuations of the energy delivered by a dc bus allows the assessment of the response of the generation system to different loading conditions.

This presentation refers to an enhanced energy measurement system for dc busses powered by renewable sources. The measurement system presumes the usage of an analog front end (AFE) based on a series connected resistor for current measurement and a voltage divider for voltage measurement. The functioning of the measurement system consists in acquiring continuously i. the signals directly collected from the AFE and ii. the same signals enhanced by means of adaptive signal conditioning blocks (SCBs). The SCBs are digitally controlled by means of a microcontroller that continuously aims to enhance the variations of the measurands. The acquisition of the signals is performed by means of an analog-to-digital converter (ADC) and a processor collects the digital data and calculates the energy and the power of the dc bus. For this purpose, both the values of the measurands obtained from the directly collected signals and those of the measurands based on enhanced signals are used. By acquiring the signals delivered by the AFE, the baselines of the voltage, current and energy can be obtained. Simultaneously, the acquisition of the enhanced signals ensures magnified insights over their fluctuations. All in all, the enhanced system provides better resolution and precision of the measurement of energy of dc busses, compared to a system that uses only the signals directly collected from the AFE. The system is provided with a serial input/ output data transmission bus for communication of the values of the measured energy and for on-the run modifications of the functioning parameters (averaging time, functioning of the SCBs, etc.).

A comparison between the presented measurement system and a system based on a commercially available integrated circuit, both applied to the measurement of energy in a 48V dc bus is presented.

Acknowledgements: M. N. Pop acknowledges financial support from the MCID through the „Nucleu" Program within the National Plan for Research, Development and Innovation 2022-2027, project PN 23 24 02 01 and support from the Ministry of Research, Innovation and Digitalization through Programme1—Development of the National Research and Development System, Subprogram 1.2—Institutional Performance—Funding Projects for Excellence in RDI, Contract No. 37PFE/30.12.2021.

Measurement of silica gel coating characteristics on copper fin tube energy exchanger

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Desiccant dehumidification has gained wide attention in the recent past due to its ability to utilize industrial waste heat, and low-grade energy sources for its function that leads to a cleaner and greener environment. In the present investigation, two fin tube samples are coated with different desiccant and binder compositions through Sol-Gel Process. The solid desiccant, binder, and coating technique chosen in this study are silica gel, hydroxyethyl cellulose, and dip coating, respectively. On the fin-tube sample, 90% - 95% of silica gel and 10% - 5% of binder compositions are chosen for assessing the optimal coating. To pre-treat the prepared composition using sol-gel method, ultrasonication is done at 25 ˚C for 9 minutes which actuates the ions of the desiccant solution. To uniformly prepare the desiccant solution, the silica gel-binder composition is stirred in a magnetic stirrer for 1.5 hours and later, the composition is subjected to an electron activation machine at 5 V and 0.75 A for 30 minutes. Measurement of the Silica Gel concentration and surface morphology of the coating onto the fin-tube sample is very crucial for optimizing the composition. Therefore, the structure and surface morphology of the fin tube samples are determined using scanning electron microscopy (SEM) for analyzing the measurement characteristics of the coating. The SEM results concluded that a thick and uniform coating is formed on the surface of the fin tube sample. Water vapor adsorption isotherm and water sorption kinetic curves of silica gel coated samples are evaluated. Further, the water uptake capacity of the two different compositions is analyzed under the given range of operating conditions. It is observed that the sample with 95 % silica gel and 5% binder composition showed a maximum water uptake capacity of 0.35 g.g-1. Moreover, the adsorption capacity of the two samples is assessed for different input parameters.

Graphical abstract Figure 1. Overview of present work.

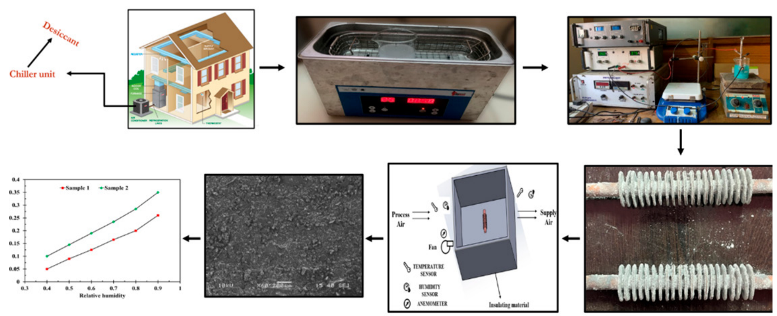

Figure 1. Overview of present work.

Influence of hydrogen addition on ammonia/air mixture in an electrical discharge ignition system

Stefan Essmann *[1], Ghazaleh Esmaeelzade[1], Jessica Dymke[1], Jacqueline Höltkemeier-Horstmann[1], Dieter Möckel[1], Carola Schierding[1], Michael Hilbert[1], Chunkan Yu[2], Ulrich Maas[2], Detlev Markus[1]

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Global warming has highlighted the need for clean and sustainable energy conversion. Ammonia has recently attracted considerable attention as a promising hydrogen carrier that can be considered as an alternative decarbonized fuel with zero carbon dioxide emissions which can be in mixtures with hydrogen. Therefore, it is essential to understand the effect of the hydrogen content in H_2/NH_3/air mixtures on the ignition process. In recent years, the prediction of combustion properties of ammonia blends such as laminar burning velocity and ignition delay times has greatly improved [1]. However, the characteristics of the forced ignition process of hydrogen blended with ammonia induced by capacitive discharge are not fully understood. To fill the lack of data, in the current study, ignition experiments by electrical discharges were carried out to analyze the ignition process of H_2/NH_3/air mixtures (the amount of hydrogen varies from 0 to 20% in the fuel). According to the experimental setup, the electrodes (with a spherical shape of 5 mm diameter and an electrode gap of 4 mm) are positioned in a spherical vessel with a volume of 0.5 L [2]. In addition, 1D numerical simulations using the in-house code INSFLA [3] provide further insight into the ignition process. The main focus of this study is to determine the ignition energy, the explosion pressure evolution, the pressure rise rate, and flame kernel development depending on the hydrogen content in ammonia/air mixture.

The results confirm that adding even a small amount of hydrogen to the ammonia/air mixtures leads to an enhancement of burning characteristics and a significant decrease in the energy required for ignition. Furthermore, the flame kernel evolution captured by schlieren imaging shows that the kernel evolution is dominated by the discharge-induced flow field and a toroidal flame shape is observed for the mixture with a lower content of hydrogen. However, for higher hydrogen contents, the hot gas kernel formed by the discharge is significantly smaller and its propagation speed is initially lower. To overcome the challenges of experimentally measuring spark characteristics such as spark radius and duration, numerical calculations provide in-depth insight into flame propagation in the earlier stages. The numerical results show that the spark radius significantly affects the flame kernel propagation, the maximum value of the product mass fraction, and the ignition delay time. Specifically, increasing the spark radius reduces the maximum temperature, resulting in a longer ignition delay time and a delayed flame kernel formation.

In conclusion, mixing hydrogen with ammonia is a feasible way to improve the ignitability of the mixture and increase the efficiency of technical combustion processes. Furthermore, the sensitive influence of H_2 addition on the ignition of NH_3-air mixtures by electrical discharges should be considered for safe handling to prevent accidents.

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Detection of CO2 leakage from pipelines and storage units under ccs conditions through acoustic emission

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CO_2 pipelines and storage units are important elements in the CCS chain, safe storage of captured CO_2 requires reliable and cost-effective monitoring techniques for detecting potential leakage from pipelines and storage units. When temperature and pressure change and impurity gases are present in CO_2 pipelines and storage units, the properties of CO_2 fluid and the geological and environmental safety of the storage site can be affected. In this research, N_2 is added to the CO_2 fluid and the mixture is then leaked to the atmosphere under controlled conditions. Along the experimental test pipelines, acoustic emission (AE) sensors and a Coriolis flowmeter were installed to enable the detection of CO_2 leak rate and the volume of the impurity gas. Data-driven models based on artificial neural networks (ANN), LS-SVM and random forest (RF) are used to measure the leak rate of CO_2 and volume fraction of N_2.

Predicting the density and uniformity of fresh concrete using ultrasonic echo pulse velocity

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The density and uniformity detection of fresh concrete is one of the key techniques in quality control of concrete construction. An ultrasonic transducer was used to detect the echo pulse velocity of fresh concrete, and a study was also carried out to predict the density and uniformity of concrete under different setting processes and different mixing times. The densities of the three stages of the concrete setting process, namely, the flow period, the setting period and the hardening period, were detected separately by the ultrasonic transmittance method, and the density values of the concrete in different periods were derived by correction, and the uniformity of the concrete was calculated under different mixing times in the flow period. The results show that the ultrasonic echo velocity shows a gradual increasing trend during the setting process of fresh concrete, while the density shows a gradual decreasing trend. The ultrasonic echo technique can effectively predict the density and uniformity of fresh concrete, and to a certain extent, it can guide the on-site construction of concrete.

An improved dTDLAS instrument for direct NO2 measurements

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Nitrogen dioxide (NO2) is an air pollutant and a strong indicator in the atmosphere for pollution from any air breathing combustion processes e.g., in transport (car/ship/planes) engines, power plants or industrial processes using fossil or biofuels, as well as hydrogen or ammonia. In the last years, there has been an increased need for quality control measurements of NO2 emitted from engine exhausts. The European EURO 5/6 vehicle emission standard states that during vehicle type approval, NO2 emissions after NOx-removal catalyst need to be within 1–30 µmol/mol while catalyst entrance levels range between 30-2500 µmol/mol depending on engine type [1]. For quality control measurements, NO2 is typically measured using the standard reference method based on chemiluminescence according to European standard EN 14211:2012. Chemiluminescence, however, cannot measure NO2 directly; instead NO2 amount fraction is indirectly calculated from a differential NO measurement before and after a (catalytic or photolytic) conversion of NO2 to NO, which can lead to an overestimation of NO2 mole fraction [1]. Recently alternative “direct” NO2 measurement methods based on laser spectroscopy are being developed [2]. Here, “first principle” or calibrated direct tunable diode laser absorption spectroscopy (dTDLAS) NO2 amount fraction measurements in exhaust gas have been shown: Particularly dTDLAS operation as an optical gas standard (OGS). An optical gas standard is dTDLAS instrument that can provide gas species amount fraction results that are directly traceable to the international system of units (SI) without requiring instrument calibration. This traceable calibration-free mode is interesting [1] to avoid the problems associated with the drift of the NO2 calibration gases.

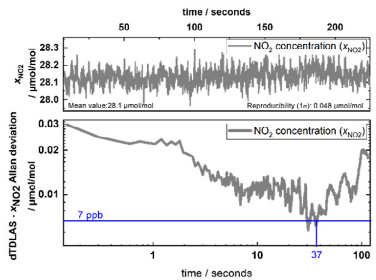

Figure 1: Top: dTDLAS NO2 amount fraction (xNO2) results at 28.1 µmol/mol (reproducibility: 1σ = 48 nmol/mol) versus time. Bottom: Allan deviation versus time.

Here, we report our improved dTDLAS instrument [1] for direct NO2 measurements in exhaust gas matrix. The instrument now contains two gas cells, i.e., a single pass and a muti-pass Herriott gas cell, in order to cover the full NO2 amount fraction range of 1-2500 µmol/mol required for the type approval emission limits quality control test (EURO 5/6). We present NO2 amount fraction results and discuss the performance of the optimized dTDLAS instrument in multi-component gas mixtures, mimicking exhaust gas. As shown in the Allan plot in Figure 1, an improved optimal precision of 7 nmol/mol (detection limit at a time resolution of 37 s) has been reached for the instrument with the multi-pass gas cell compared to 825 nmol/mol (detection limit at a time resolution of 86 s) with the single pass cell only as reported in [1].

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Structural health monitoring of wind turbine blades using image processing methods

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The operation and maintenance costs of wind turbines are growing as their sizes grow bigger. This poses a challenge especially for structural health monitoring of large wind turbines. One monitoring aspect is the rotational speed of wind turbine blades. Sudden changes in the rotational speed indicate possible damage in the controller or gearbox. In general, rotational speed of wind turbine blades can be measured in various ways, from ultrasound sensors, photogrammetry to the state-of-the-art image correlation method with frequency analysis. Although proven to be very accurate, they cannot provide instantaneous speed measurements. Another monitoring aspect is the vibration of wind turbine blades, which may be caused by wind perturbations or ice buildup. Vibration of wind turbine blades is typically monitored using built-in sensors such as inertial sensors, Fiber Bragg Grating (FBG) sensors as well as strain gauges. These sensors are usually installed during the manufacture process of the blade. For example, strain gauges can be laminated onto the surface of the blade; and FBGs are glued when combining the top and bottom composite shells. As a result, it is nearly impossible to conduct maintenance or replace these sensors if they are faulty. Due to the advantage of non-contact measurement, a camera carried by an UAV (Unmanned aerial vehicle) with appropriate imaging processing methods provides an alternative solution to overcome the shortcomings mentioned above.

In this paper, a marker tracking method is proposed to measure the instantaneous rotational speed and vibration of wind turbine blades. The proposed method is compared with the commonly used image correlation method through experimental study to assess their performance. Experimental tests were conducted to investigate the effects of varying speed, the configuration and installation of the camera and environmental conditions on the measurements. Initial experimental results demonstrate that the relative error of rotational speed measurement is mostly between ±2.5%, in the measuring range of 5 - 30 rpm using the marker tracking method. The marker tracking method is more efficient and simpler to implement and is capable of providing instantaneous measurements, while the correlation method has a longer response time.

Standard methodology for flammability determination and experimental test with different fuels

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The flammability limits of fuel are the key to fire prevention, assessing the risk of explosion and designing protection systems. Fire and explosion prevention plays an important in industrial and domestic safety. The flammability limits refer to the range of compositions for a combustible/oxidizing mixture, within which flame propagation is possible when an external ignition source is introduced. There are two limits of flammability, the lower or fuel lean and the upper limit or fuel rich Currently, different experimental tests and criteria (visual or/and pressure) are used to determine the flammability limits of fuels leading to different experimental values. The temperature, pressure, ignition source, type (spherical or cylindrical) and volume of the container among others affect the final result. In this study, the different modern experimental methodologies for the determination of the upper and lower limits of flammability of liquid fuels in air are discussed. For example, the experimental flammability limits were determined for benzene/air and cyclohexane/air mixtures at atmospheric pressure and a temperature of 50°C. The increase in pressure inside the container was used as a criterion to decide if the fuel is flammable or not; a fuel is flammable, if the increase of pressure is ≥ 5% of the test initial absolute pressure, this criterion is in line with the European standard. A spherical vessel of 8 L (inner diameter 250 mm) with 2 optical access quartz windows (60 mm) was used in the experiments. The ignition source was manufactured according to the European standard (EN 1839). A series of sparks are inducted by electrodes in in the centre of the vessel, the electrodes are spaced 32 mm apart and the total energy emitted by the sparks is around 2 J per 0.2 s of average discharge time. The energy deposited by the sparks depended on the mixture for each test. A parametric logistic distribution function is used to calculate the flammability limits of fuels to avoid any true false signal. The experimental results obtained for the fuel/air mixtures were compared with data published in the scientific literature.

Traceable ammonia quantification and metrological uncertainty evaluation in a shock tube

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Department of Physical Chemistry, Physikalisch-Technische Bundesanstalt Braunschweig, Lower Saxony, Germany

Ammonia (NH3) is a promising alternative fuel due to its carbon-free feature. However, the emission of ammonia is one most unwanted drawbacks and needs to be solved by quantitative measurement of its footprint in the entire energy conversion process. As in a combustion chamber, a highly dynamic reactive environment exists generally, and it is a big challenge to accurately probe the speciation variation in it. Shock tubes are typically applied to create a quasi-instantaneously and homogeneously high-temperature and pressure environment with test times of a few hundred microseconds to several milliseconds which are suitable for characterizing dynamic gas sensors.
Given this, we developed and validated an ultra-rapid spectrally resolved tunable diode laser absorption spectroscopy (TDLAS)-based spectrometer with a scan frequency of 40 kHz and coupled it with the shock tube for dynamic NH3 quantification. Thanks to the high scan frequency, the NH3 mole fraction at various stages during the dynamic process can be quantified, covering a wide temperature range of 295-3348 K and a pressure range of 0.02-3.15 bar. In addition, considering lacking metrology in shock tubes for dynamic studies, we comprehensively evaluated the uncertainty sources and budgets of thermodynamic parameters and species concentration based on Guide to the expression of uncertainty in measurements (GUM). The established metrological uncertainty evaluation method for shock tube experiments can be beneficial to provide traceable and high-quality data, which is vital for chemical kinetic modeling.

Metrology support for carbon capture utilisation and storage

Iris de Krom, Kurt Rasmussen, Rod Robinson, Noor Abdulhussain, Simona Lago, Alexandra Kostereva

The European Green Deal set targets to reduce greenhouse gas emissions by at least 55% by 2030 compared to 1990, and net zero emission of greenhouse gases by 2050. This is necessary to overcome climate change and environmental degradation worldwide. Carbon dioxide (CO2) is the primary greenhouse gas emitted from fuel combustion and industries like cement, steel, and refineries. Carbon Capture Utilisation and Storage (CCUS) can provide a key solution to decrease the CO2 emissions by capturing, transporting and storing it permanently underground. Alternatively, captured CO2 can be converted to obtain carbon-neutral fuels, chemicals, minerals, or biofuels, or it can be used in industrial applications, such as the food and beverage industry.
The MetCCUS project (Metrology Support for Carbon Capture Utilisation and Storage – 21GRD06) within the European Partnership on Metrology will address the key measurement challenges related to, e.g., flow metering, emissions monitoring, purity assessment and understanding physical properties of CO2. For these challenges, primary standards, calibration and measurement methods and good practice guides will be developed. In order to facilitate efficient and safe usage of this technology and to support the EU Emissions Trading System (EU ETS) and the CCUS industry. An overview of the MetCCUS project goals and impact will be presented.

The Metrology Partnership 22IEM03 project "Primary Spectrometric Thermometry for Gases"

Gang Li

Working Group 3.42, Physikalisch-Technische Bundesanstalt, Braunschweig, Germany

Global warming has become one of the top challenges for humans. Severe effects are exemplified by record drought and flooding on several continents including Europe this year. Europe will be the most affected region predicted by IPCC. Accurate air temperature measurements are critical for climate change monitoring and the related evidence-based policymaking for early mitigation/adaptation planning.
Spectrometric thermometry overcomes several practical challenges posed by contact thermometry in air and industrial processes. However high uncertainties in molecular spectral parameters and adoption to elevated temperatures hinders its use. The consortium will integrate the knowledge and infrastructure across the EU to improve, standardise and implement novel, non-contact methods including primary ro-vibrational spectroscopic thermometry. This will be cross-validated against other non-contact and the ITS-90 standard methods. Ultimately, a new hybrid calibration service with minimal long-term drift will support SI-traceable calibration of classical contact thermometers in gas and air.
The overall objective of the project is to define and develop a new primary traceable spectroscopic gas temperature measurement approach over a temperature range of 200 – 400 K with a target uncertainty of 10mK.

The project objectives are:

1. To perform high accuracy quantum mechanical calculations on essential line parameters (line intensities and their rotational and vibrational dependence) of selected ro-vibrational bands of candidate "sensor" molecules (e.g., CO, CO2, O2) for temperatures in the range of 200 K to 400 K.
2. To perform high accuracy measurements of optimal selected molecular transitions (e.g., CO, CO2, O2) using high-resolution Fourier-transform spectroscopy (FTS) infrastructure, comb-assisted cavity ring-down spectroscopy (CA-CRDS) such as Doppler Broadening Thermometry (DBT), Cavity Mode Dispersion Spectroscopy (CMDS) and comb-based broadband techniques. To retrieve essential line parameters with high accuracy using refined line shape models (e.g. IUPAC recommended Hartmann-Tran profile). To compare and validate the ab initio results from objective 1 using the best experimental values.
3. To develop the methodology of multi-line ro-vibrational spectrometric gas thermometry (RVSGT) and to evaluate its performance under metrologically controlled laboratory conditions in the range of 200 K to 400 K, adopting spectral parameters from objectives 1 and 2. To develop the infrastructure for primary gas temperature measurements by updating existing NMI FTS infrastructure with a target uncertainty of 25 mK, to correspond to 0.1 % accuracy in relative line intensities of the probed molecular absorption lines.
4. To cross-validate spectrometric gas thermometry from objective 3 against other methods for the determination of thermodynamic temperatures (e.g., DBT, refractive index gas thermometry (RIGT), or via ITS-90 referenced SPRTs and T-T90) maintained at NMIs. To adapt the NMIs' optimum experimental capacities and proven test scenarios to identify further opportunities to improve the uncertainty to 10 mK.
5. To demonstrate the establishment of an integrated European metrology infrastructure for primary spectrometric thermometry for gases and to facilitate the take up of the technology and measurement infrastructure developed in the project by the measurement supply chain, European and international technical committees on thermometry (CCT, EURAMET and other RMOs TCs) and end users (remote sensing, automobile industry and aerospace industry).

Call for papers in the Measurement Journal

A special issue of the Measurement Journal will be published following the conference. Authors who have presented their papers at the conference are invited to submit full papers to the special issue by 1st of December 2023. The usual review procedure of the Measurement Journal will be applied.

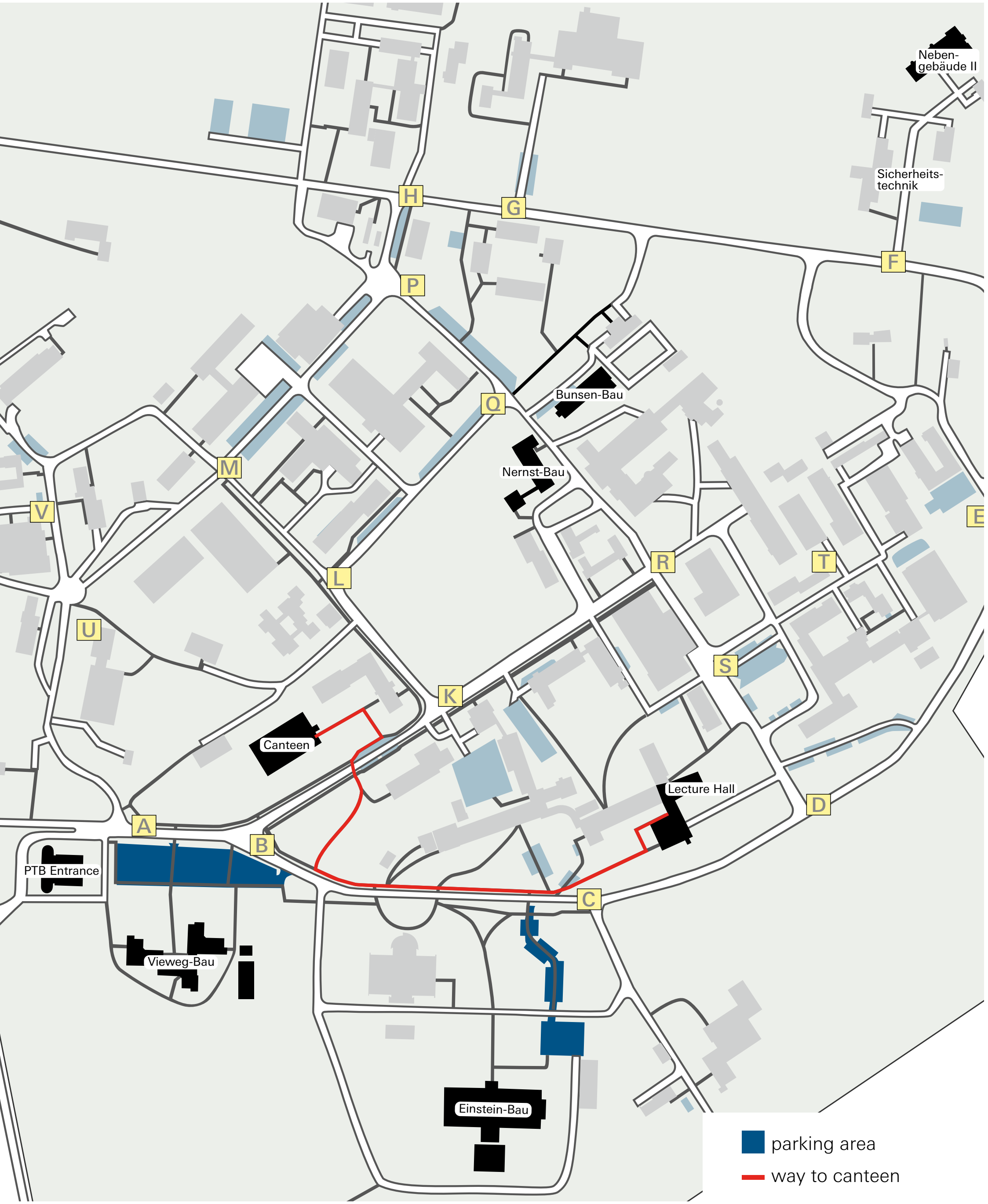
The Guest Editors for this special issue are Dr Wenbiao Zhang (North China Electric Power University), Dr Lijuan Wang (University of Kent) and Prof. Dr. Yong Yan (University of Kent).

Impact factor: 5.131 | Cite Score 7.8

Measurement: Journal of the International Measurement Confederation (IMEKO)

Contributions are invited on novel achievements in all fields of measurement and instrumentation science and technology. Authors are encouraged to submit novel material representing achievements in the field, whose ultimate goal is an enhancement of the state-of-the-art of subjects such as: measurement and metrology fundamentals, measurement science, sensors, measurement instruments, measurement and estimation techniques, measurement data processing and fusion algorithms, evaluation procedures for performance analysis of measurement systems, processes and algorithms, mathematical models for measurement-oriented purposes, and distributed measurement systems in a connected world.

Map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