GREEN DEAL
ORIENTATION PAPER

TC for Thermometry (T)
TC Chair: Dolores del Campo
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ORIENTATION PAPER ON CHALLENGES IN THERMOPHYSICAL QUANTITIES METROLOGY

Thermophysical properties (radiative properties, thermal transport properties and caloric quantities) are key parameters in all applications involving heat transfer phenomena. The knowledge of the thermal behaviour of materials in condition of use is needed in order to optimize the performance of the concerned components and to contribute to their sustainability.

The concerned areas are numerous and varied, ranging from production and storage of energy to heat transfer in buildings, passing through micro- and nano-scale technologies (microelectronics, thin films ...) and industrial processes (e.g. additive manufacturing). In all these fields, it is essential to have reliable and accurate data on thermophysical properties of the used materials as a function of temperature.

This section of the orientation paper presents the main R&D priorities identified in the field of thermophysical properties metrology that should be addressed in order to meet the needs defined in the following policy areas (https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en#policy-areas) of the European Green Deal: Clean energy, Sustainable industry, Building and renovating, and Sustainable mobility.

1. **Clean Energy** (decarbonising the energy sector)

One of the key principles of the European Green Deal to ensure the decarbonisation of the EU's energy system is to prioritise energy efficiency and to develop a power sector based largely on renewable sources. The thermophysical properties metrology can contribute to this challenge for different types of non-fossil energies through several R&D activities.

1.1 Solar energy

There are metrological needs for the two electricity production technologies based on solar energy: photovoltaic systems and concentrated solar power (CSP) systems.

- *Measurements of the thermophysical properties of thin films and optical materials (absorbers, mirrors, especially at very high temperatures...),*
- *Thermal characterisation (density, viscosity, specific heat, thermal conductivity) of energy storage materials (molten salts, phase change materials).*

1.2 Nuclear energy

Even if nuclear energy cannot be considered as renewable energy, it is an alternative energy source to fossil fuels, which could be potentially used (as well as solar energy) for the production of hydrogen (cf. § 1.3). Nuclear energy is one of industry sectors whose applications require reliable determination of high temperature thermophysical properties:

- *Improvement of the traceability of thermal expansion measurements at high temperature,*

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EURAMET e.V., Bundesallee 100, 38116 Braunschweig, Germany
Phone: +49 531 592 1960 Fax: +49 531 592 1969 E-mail: secretariat@euramet.org
www.euramet.org

- *Extension of the temperature range of existing metrological facilities for the thermal performance analysis of materials at very high temperature (specific heat, emissivity, thermal conductivity and thermal diffusivity measurements)*

To support the R&D of fusion based nuclear energy, the temperature range of the existing metrological facilities need also to be extended for measuring thermophysical properties of superconductors at cryogenic temperatures.

1.3 Hydrogen energy

Decarbonisation of gas grids allows reducing the dependence from fossil source of energy in favour to a sustainable, efficient, clean and neutral use of energy resources. The main identified needs of industry in that area are:

- *Gross calorific value measurements of biomethane or hydrogen-enriched natural gas,*
- *Supply of improved thermodynamic data for determining physical properties of hydrogen, biomethane or hydrogen-enriched natural gas in the grid, or carbon dioxide for Carbon Capture and Storage (CCS),*
- *Development of accurate models describing thermophysical properties of complex mixtures of enriched natural gases,*
- *Characterisation of thermal properties of materials used for the storage and transportation of hydrogen and liquefied natural gas* (LNG) ⇨ Measurements at cryogenic temperatures.

1.4 Wind energy

Wind energy has become the largest form of renewable power generation capacity in Europe. The growing demand for the green energy has forced investors in power industry to look for resources further out at sea. In the future, offshore wind farms will likely be located more than 100 miles from shore. The main challenge in the development of large offshore wind power projects lies in reliable and efficient transmission of power generated by an offshore plant to the onshore electricity grids. Measurement techniques need to be developed, validated and standardized to enable reliable characterisation of thermal performances of material systems and surrounding environments for the power transmission systems. Reliable thermophysical properties data are required for the quality assurance of the design, operation and maintenance of the power transmission systems from large offshore wind farms to onshore national grid.

2. **Sustainable industry** (supporting industry to develop environmentally-friendly technologies and to innovate)

A climate neutral and circular economy requires the development of sustainable product policies, in order to reduce the consumption of energy and resources and production of waste during manufacture and also after use by enforcing recycling strategies. Here, the supply of sustainable raw materials can only be achieved by diversifying supply from both primary and secondary sources (especially for critical raw materials necessary for clean technologies, digital, space and defense applications).

With raw materials coming from a variety of different sources, reliable product quality can only be achieved with increased material testing with respect to thermophysical properties (and ideally in situ during manufacturing or onsite).

Thermal characterization of materials is essential in many fields of industry in order to improve the energy efficiency of industrial processes, and to support energy saving or energy harvesting in new high-tech innovative materials and devices.

Depending on the cases, this requires the adaptation of existing measurements methods (e.g. extension of the range of measurements in terms of dimension or temperature) or the development of new ones, for the following applications:

- *Characterisation of thermal protection materials at medium and high temperature,*
- *Thermophysical properties measurements of composite materials or materials for additive manufacturing (e.g. for metallic powders, solids and melts),*
- *Thermal characterisation of superconductor materials at very low temperature,*
- *Measurement of thermal transport properties at micro- and nano-scales (quantum technologies, nanostructured materials, electrocaloric/magnetocaloric materials…),*
- *Establishment of comprehensive reference data sets to enable virtual validation,*
- *Study of the thermophysical properties and phase behavior under confinement,*
- *Establishment of equations of State (EoS), models and correlation equations for solid and fluid energy related materials,*
- *Thermodynamical characterisation of new solvents (e.g. ionic liquids), fuels and products coming from Green Chemistry (organosilicon compounds, biocatalysts…).*

3. **Building and renovating** (ensuring buildings are more energy efficient)

A better knowledge of the thermophysical properties of building envelopes materials is required to increase the energy performance of buildings (by reducing the energy losses). Existing metrology in that field need to be improved in the following domains:

- *Characterisation of super-insulation materials (porous materials, materials with significant internal radiative transport),*
- *Onsite characterisation of building insulation materials,*
- *Development of reference materials to support traceability of thermal conductivity measurements performed with commercial heat flow meters,*
- *Characterisation of advanced coatings for passive solar thermal management.*

4. **Sustainable mobility** (rolling out cleaner, cheaper and healthier forms of private and public transport)

One of the objectives of the Green Deal is to boost supply of sustainable alternative transport fuels and to reduce by 90 % greenhouse gas emissions in transport by 2050. In addition to the R&D activities listed in §1.3 and linked to the use of hydrogen as energy vector, the thermophysical properties metrology can help the automotive industry in the development of low carbon vehicle technologies (hybrid electric or electric vehicles) in the following subjects:

- *Thermodynamical characterisation of refrigerants of new generation and new lubricants,*
- *Thermophysical properties characterisation of materials for thermal management (e.g. materials for thermal comfort automotive, interface materials, new generation of power electronics, battery modules) of EVs and HEVs,*
- *Study of thermal properties of biofuels and transition fuels (blending fossil and non-fossil fuels).*