Publishable Summary for 22RPT03 MultiFixRad
Improving the realisation of the kelvin by multiple fixed-point radiation thermometry

Overview

Highly accurate and traceable high temperature measurements are critical to a number of European industries, including metallurgical industries, glass, graphite and fertiliser production. Currently, there are regional gaps in the dissemination of the temperature scale with primary techniques at high temperatures. The *mise-en-pratique* of the new definition of the kelvin (*MeP-K*) offers new possibilities to realise and disseminate thermodynamic temperature using multiple high-temperature fixed points to calibrate a radiation thermometer, which is then used as an interpolating instrument. The project aims to assist 6 less experienced European national metrology institutes and designated institutes (JV, RISE, DFM, CMI, SMU, and UL) in establishing their own primary reference scales for thermometry using this approach. The improved high-temperature measurement standards will respond to industrial needs in the countries and enable participation in development projects for fundamental thermometry at high temperature, and at the highest scientific level.

Need

The recent redefinition of the kelvin, and the new *MeP-K*, opens up a new pathway for dissemination of the temperature scale. The most common instruments for disseminating temperature remain thermocouples for temperatures up to around 1500 °C, but these require calibration against primary references. The less experienced institutes in this project (JV, RISE, DFM, CMI, SMU and UL) are all well-established intermediate level national metrology institutes (NMIs) and designated institutes (DIs) in Europe, but they currently lack a realisation of high temperature primary standards. The participants represent countries with substantial production, processing, and manufacturing industries with expressed needs for improved high temperature standards, including the metallurgical industry, manufacturing of building materials and H_2 production.

Following the recent redefinition of the kelvin one of the most promising primary reference standards for high temperature is to interpolate between high temperature fixed points, whose transition temperatures have been established with high accuracy, using a radiation thermometer as the interpolation instrument. However, the method has not yet been implemented on a large scale outside the major NMIs. An important pillar of the metrological community is the ability to compare results across different institutions and countries, but this requires that a certain number of institutes are capable of realising the quantity to be compared. To address these aims some less experienced NMIs/DIs need to develop primary thermometry capabilities, including the ability to construct, characterise, use and maintain fixed points intended for radiometric applications, and to establish a primary temperature scale in line with the revised MeP-K. By taking a coordinated approach this will help the European metrology community to improve its robustness, but at the same time avoid fragmented and uncoordinated capacity building. The consortium will create nascent regional centres of excellence in the field, by coordinating the activity in the Scandinavian and central European regions, respectively.

Objectives

The overall objective of this project is to endow six European NMIs (JV, RISE, DFM, SMU, CMI and UL) with the competence and resources to realise a primary high temperature scale at the highest level, in accordance with the revised MeP-K. The specific objectives are:

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1. To transfer knowledge to the less experienced institutes on the theoretical and experimental aspects of the realisation of the ITS-90 by extrapolation from a single fixed point. An important part of this includes knowledge about the characterisation of the radiometer used to extrapolate temperature, such as its size-of-source sensitivity, linearity and spectral response.
2. To construct a set of medium- to high-temperature fixed points for radiation thermometry adapted to the technical means of less experienced NMIs/DIs. This includes assessment of the quality of the cells and experimental determination of the optimal thermal conditions for their use.
3. To realise the MeP-K through the application of the multi fixed point scheme using a variety of radiation thermometers and temperature ranges in accordance with the needs of less experienced NMIs/DIs, and to compare several realisations to the ITS-90. The target uncertainty of the realisations is 0.6 °C at 1500 °C and 1 °C at 2000 °C.
4. To perform an interlaboratory comparison, aiming to establish linkage to key comparison CCT-K10, to underpin improved calibration and measurement capabilities (CMCs) for participant laboratories in the field of radiation thermometry.
5. To facilitate the take up and long term operation of the capabilities, technology and measurement infrastructure developed in the project by the measurement supply chain (NMIs/DIs, calibration and testing laboratories), standards developing organisations (e.g. CIPM CCT, EURAMET TC-T), and end users (e.g. metal forming, building insulation, and steam reforming).

Progress beyond the state of the art and results

Knowledge transfer on the theoretical and experimental aspects of using ITS-90 and high-temperature fixed points

Above the freezing point of Ag (961.78 °C), the ITS-90 [1] is defined by extrapolating the Planck radiation from a blackbody at either the Ag, Au or Cu fixed points. While many laboratories perform some sort of scale dissemination this way, few have the capabilities to carry out a thorough characterisation of the pyrometer used in the extrapolation, including control of the linearity, spectral response and size-of-source (SSE) sensitivity. Leveraging CNAM's, LNE's and TUBITAK's extensive experience and competence in thermometry, personnel from the less experienced NMIs/DIs (JV, CMI, SMU, RISE, DFM and UL) will be trained in the relevant aspects of high temperature pyrometry, including the determination of thermodynamic temperature for a range of high temperature fixed points and the characterisation of radiometers. In addition, the opportunities for smart specialisation in the Scandinavian and the central European regions will be explored.

Construction of medium and high-temperature fixed point cells

High temperature fixed points are non-trivial to construct, characterise and use. Some fixed point cells are prone to damage, which means that a laboratory must expect to regularly replace or characterise their cells. While some of the less experienced laboratories have some limited previous experience with a small set of high temperature fixed points, none of them currently have experience of the construction nor characterisation of cells for radiometric use. Again, CNAM, LNE and TUBITAK will provide expertise, including know-how from earlier projects SIB01 InK, 15SIB02 InK 2 and 18SIB02 Real-K, to enable the less experienced institutes to acquire the necessary capacity to construct, characterise, use and maintain fixed points intended for radiometric applications in-house in the long run. The cells constructed will include Al (660.323 °C), Ag (961.78 °C), Cu (1084.62 °C), Fe-C (1154 °C), Co-C (1324.24 °C), Pd-C (1492 °C), Pt-C (1738.28 °C) and Re-C (2474.69 °C). To build this capacity without support would take many years, however within the project this process is shortened dramatically.

To realise the new MeP-K through a multi-fixed point scheme

The current scale realisation at the participants is either based on thermocouple calibration at fixed points from the intermediate range from 660 °C (Al freezing point) and upwards, or radiometric extrapolation in line with ITS-90, but with relatively high uncertainties. None of the less experienced institutes have a primary realisation of temperature according to the revised MeP-K. In this project the less experienced institutes will be equipped with the experience, skills and knowledge to implement a continuous temperature scale using interpolation between 3 or more high-temperature fixed points. The target uncertainty of the realisations is 0.6 °C at 1500 °C and 1 °C at 2000 °C. The consortium will also explore an interpolation scale for intermediate temperatures, which aims to rival thermocouples from 660 °C and upwards. New measurements will be carried out on the aluminium and silver points, using the extrapolation technique of ITS-90 to scale the radiometric measurements down from the Cu point.

To perform an interlaboratory comparison with the possibility of linkage to CCT-K10

Currently none of the less experienced laboratories can connect with key comparisons in the field. A comparison will be organised and performed to document and validate the new temperature scale realisations at the less experienced NMIs/DIs. The comparison will enable the participating institutes to link to the CCT-K10 via the French institutes (LNE and CNAM). The results of the comparison will also provide a first testcase for the new MeP-K. If successful, the comparison will strengthen the idea that the interpolation scheme is a viable path to realise a thermodynamic temperature scale beyond the highest-ranking institutes.

Outcomes and impact

Outcomes for industrial and other user communities

The new capabilities established in this project will aid regional accredited laboratories and industrial stakeholders. A number of energy intensive industrial processes, such as metallurgical processing, fertilizer, glass and graphite production, take place at high temperatures in excess of 1000 °C, where the accurate control of temperature may affect the quality of the end product. With improved reference standards, the NMIs and DIs will be able to supply stable and precise calibration services to regional customers, which in turn will enable improved temperature measurements in industrial applications. Precise reference standards pave the way for new techniques for applied thermometry, which in turn may lead to improved process control. The project will demonstrate examples of the dissemination of the new scale at three industrial environments during the project. One method will be by transfer using an interpolation instrument calibrated at fixed points, which is close to the traditional way to transfer traceability. A second method will deploy a calibrated fixed point at the factory to enable a local calibration directly against this point. If successful, this will directly enhance the temperature measurements at the end users.

Outcomes for the metrology and scientific communities

The direct outcome of this project will be to assist six less experienced European NMIs and DIs (JV, RISE, DFM, CMI, SMU and UL) to establish a primary temperature scale in line with the revised MeP-K that followed the redefinition of the kelvin in 2019. In particular the participants will implement the interpolation scheme, where precise radiometers are used as interpolation instruments that are calibrated using three or more temperature fixed points. This will enable these institutes to (i) be in a position to submit CMCs for new or improved calibration services within the range 961.78 °C to 2474.69 °C, (ii) help disseminate a more precise high temperature scale in Europe, and (iii) contribute to future research and collaborations in high temperatures, such as the European Partnership on Metrology calls on Industry, Integrated European Metrology and Fundamental Metrology. The less experienced NMIs/DIs will all benefit from a potential opportunity to link to the CCT-K10 key comparison, as this will help document their measurement capability at the end of the project and allow them to register updated and improved CMC values in the Key Comparison database. An important aim with this project is to foster regional collaboration and specialisation within EURAMET. The consortium consists of European NMIs and DIs that conveniently cluster in two regions, the Scandinavian and central European regions. This enables the consortium to create centres of excellence to cover regions beyond individual countries. The strategic outlook of CCT for the 2020s calls for further development and dissemination of primary thermometry techniques, and this project will enable the less experienced institutes to contribute to this work.

Outcomes for relevant standards

The new MeP-K acknowledges the interpolation scheme as a primary thermometry method, but it has not yet been implemented beyond the largest NMIs. The project will produce the first technical guide for the implementation of a thermodynamic temperature scale. The aim is for this to eventually be a EURAMET guide, and it will be developed to fulfil the needs expressed by the EURAMET TC-T but also the CCT. The experience from work within the project is expected to inform the CCT on relevant aspects of the new MeP-K.

Longer-term economic, social and environmental impacts

There are a number of industrial processes with high importance for the green transition that involve processing steps at high temperature, which are widely employed in the countries represented in the consortium. Examples range from the manufacturing of solar cells, steam reforming for H_2 production, the production of graphite for Li-ion batteries, to manufacturing building insulation materials. High temperature measurement is also important in combustion processes, such as ICE engines, waste incineration or power plants. Improved high temperature standards and measurements are the basis for optimising these processes, which in turn may improve product quality, enhance efficiency, and reduce the resource footprint of the processes.

List of publications

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This list is also available here: https://www.euramet.org/repository/research-publications-repository-link/

<table>
<tr><td colspan="2">Project start date and duration:</td><td>01 June 2023, 36 months</td></tr>
<tr><td colspan="3">Coordinator: Åge Andreas Falnes Olsen, JV Tel: +47 988 10 363 E-mail: aao@justervesenet.no
Project website address: -</td></tr>
<tr><td>Internal Beneficiaries:
1. JV, Norway
2. CMI, Czechia
3. CNAM, France
4. DFM, Denmark
5. LNE, France
6. RISE, Sweden
7. SMU, Slovakia
8. TUBITAK, Türkiye
9. UL, Slovenia</td><td>External Beneficiaries:
10. DTU, Denmark</td><td>Unfunded Beneficiaries:
-</td></tr>
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