Annex 1 – Research Schedule

Version Date: 29 June 2021

18SIB02-RMG2

Adiabatic triple point of carbon dioxide

Researcher
Peter Pavlasek
SMU

A. Contract will start[1]: 01 04 2022
B. Funding for 4 months' work at the guestworking organisation[2]
C. The earliest date for the contract to end is A+ X months[3]: 31 07 2022
D. The latest date for the contract to end is A+ X + 6 months[3]: 31 01 2023

---

[1]Work can commence at the guestworking organisation at any time after this date
[2]EURAMET will distribute the allowances once the researcher confirmed a start date.
[3]15 % will be retained by EURAMET until the Final Report is approved. Researcher should inform EURAMET well in advance of the end date.

Contents

Section A: Research outline

Overview

The Need for This Research: In November 2018 the international system of units (the SI) was redefined in terms of fundamental constants with defined values. Amongst the affected basic SI units was the unit of thermodynamic temperature the kelvin (*K*), which is now defined in terms of the Boltzmann constant. This change of the unit's basic definition requires further investigation, and the development and adoption of primary thermometry techniques which can be practically used to realise and disseminate the newly defined kelvin. As the International Temperature Scale of 1990 (ITS-90) represents a technique for pragmatically providing traceability to the basic unit of *K*, it needs to evolve with respect to the new definition. The current ITS-90 has been in use for several decades without any significant revision, and in the light of the newest development, several areas of the scale need to address the current progress in temperature metrology. Areas that need to be investigated to take into account the novel development in thermometry include the introduction of new measurement and mathematical methods and alterative fixed-point cells. This RMG's research will focus on the last of these listed areas, specifically the investigation of the fixed-point cell (FPC) of carbon dioxide (CO_2) that should be a potential substitute for the currently used FPC of Hg, which contravenes the EU mercury regulation 2017/852 that restricts the use of Hg. Finally, it will provide a possible alternative to the sulphur hexafluoride (SF_6) FPC that is currently in development.

How This Research Relates to the JRP:

This RMG will build on the primary thermometry measurement research being undertaken in EMPIR JRP 18SIB02 Real-K, as it will use the state of the art SF_6 FPC and all of the measurement techniques that are required for the determination of the essential metrological parameters that are needed for the characterisation of the CO_2 triple point cell. Specific parts of the JRP that are linked to the RMG include A3.2.1 - A3.2.5. The RMG's results will enable 18SIB02 Real-K to deliver the primary thermometry results needed to facilitate an effective and practical realisation of the redefined unit K which will most likely result in the modification of the currently used ITS-90. The CO_2 FPC might also be suitable to be used as a replacement for the Hg FPC.

Projected Impact of the Research:

The SF_6 cell has the potential to become the next substitute cell for the Hg FPC in the short term, but its suitability has not been completely demonstrated yet. If SF_6 proved to have unsatisfactory metrological characteristics, an alternative has to be studied. The temperature of the CO_2 triple point (216.59 K) is close to that of Hg and SF_6, making this another potential candidate to replace Hg in the ITS-90. This RMG will ensure the calibration of thermometers in the low temperature ranges that are important for medical, industrial and chemical applications, as well as ensuring traceability to the new basic SI unit of temperature *K*.

Summary

The main objective of this RMG is to design, manufacture and characterise a prototype CO_2 triple point cell. A literature survey will be performed to define the most suitable and efficient design for the CO_2 triple point cell. An initial virtual design will then be created that is compatible for realisation in commonly available thermostatic devices. The essential dimensions and gas tightness of the manufactured CO_2 triple point cell will then be checked before it is filled with CO_2. After the cell's assembly, a series of FPC realisations will be undertaken using SPRTs or capsule type SPRTs to characterise the adiabatic realisation of the CO_2 cell. At least four adiabatic realisation scenarios will be performed and analysed in order to quantify the repeatability and stability of each scenario. The analysed data will be used to determine the most suitable layout of the CO_2 triple point cell. Furthermore, this data will be used to optimise the initialisation process in order to achieve the best possible uncertainty values.

Section B: Technical work

B1 Task 1: Design, manufacture and testing of a carbon dioxide (CO_2) triple point cell

The aim of this task is to design, manufacture and test a CO_2 triple point cell for use in the calibration of Standard Platinum Resistance Thermometers (SPRTs) or capsule type SPRTs.

The research activities within the task will be:

- **A1.1** - The RMG researcher, with support from CNAM, will conduct a literature survey of triple point cell designs, which make use of substances similar to CO_2 (e.g. $C_{10}H_{22}$, CCl_4, $C_{12}H_{26}$) in terms of their phase transition or equilibrium state stability and repeatability. The focus of this survey will be to define the most suitable and efficient design for the CO_2 triple point cell that will enable the calibration of SPRTs or capsule type SPRTs. CNAM will provide input from JRP Task 3.2.

- **A1.2** - The RMG researcher, with support from CNAM and a manufacturing company, which will be selected in the first month of the RMG based on their capabilities to manufacture pressurised vessels, will create a virtual design of the CO_2 triple point cell based on the report prepared in A1.1. The design will be compatible with SPRTs and capsule type SPRTs and it will be suitable for realisation in commonly available thermostatic devices (e.g. alcohol baths). CNAM will provide input from JRP A3.2.1.
- **A1.3** – The RMG researcher, with support from CNAM, will arrange for the manufacturing company selected in A1.2 to manufacture and deliver at least two CO_2 triple point cells based on the final design from A1.2 within the first five weeks of the RMG. They will then check the essential dimensions and gas tightness of the manufactured CO_2 triple point cells. After meeting the set checks, at least one of the manufactured CO_2 triple point cells will be filled with CO_2 (the second cell will only be used as a backup). The filling pressure of the CO_2 gas will be recorded to enable the subsequent realisation of the triple point cell. CNAM will provide input from JRP A3.2.1.

B2 Task 2: Preliminary measurements and the characterisation of a CO_2 triple point cell

The aim of this task is to characterise and perform preliminary measurements with a CO_2 triple point cell in order to determine the measurement traceability, the final measurement uncertainty budget and the optimised realisation procedure for this setup.

The research activities within the task will be:

- **A2.1** – The RMG researcher, with support from CNAM, will select at least one of each of the most suitable SPRTs and capsule-type SPRTs for use CNAM's CO_2 FPC. They will be selected on the basis of their calibration performance in the temperature range from -189.3442 °C to 0.01 °C. CNAM will provide input from JRP A3.2.2 for use in the selection of the SPRTs and capsule-type SPRTs.
- **A2.2** – The RMG researcher, with the support from CNAM, will measure the reproducibility and stability of the devices and installations (e.g. the resistance bridge, reference resistor, thermostat etc.) that will be used for the realisation of the CO_2 FPC. The measurement results will be used as inputs into the uncertainty budget, which in its combined and expanded form, is expected to be < 0.60 mK. CNAM will provide relevant data and the measurement devices needed to determine the reproducibility and stability of the devices and installations that will be used for the realisation of the CO_2 FPC.
- **A2.3** – The RMG researcher, with support from CNAM, will analyse the measurement data from A2.2 and this will be incorporated into the uncertainty budget. The analysis will use existing information including, the Guide to the Expression of Uncertainty in Measurement (GUM), and BIPM CCT and EURAMET TC-T documents and guides. CNAM will supervise the evaluation of the measured and gathered data and will furthermore conduct the final check of the calculated values of the specific point of the uncertainty budget.
- **A2.4** – The RMG researcher, with support from CNAM, will use the CO_2 triple point cell from A1.3 to perform at least four CO_2 triple point cell realisations during which all of the selected SPRTs or capsule type SPRTs from A2.1 will be calibrated. Using preliminary data from these calibrations, the procedure will be modified in order to provide the best possible CO_2 realisation stability, repeatability, and duration and slope of the plateau. CNAM will provide the required measurement devices, guidance on their operation and the measurement procedure from JRP A3.2.2.
- **A2.5** – The RMG researcher, with support from CNAM, will analyse the measurement data from A2.2, A2.3 and A2.4 to form the final measurement uncertainty budget. The analysis will define the reproducibility and stability of the realisation and other possible factors (e.g. amount of heat pulses, SPRT self-heating level, set bath temperature etc.) that affect the realisation of the FPC. CNAM will supervise the evaluation of the data and will check the final calculations.
- **A2.6** – The RMG researcher, with support from CNAM, will evaluate the results from A2.1, A2.3 and A2.5 and will prepare a report of the CO_2 FPC realisation conducted within A2.4. CNAM will supervise the evaluation of the data and will final check the report.

Section C: Impact and management

C1 Task 3: Creating impact

The aim of this task is to inform the metrology and end user communities of the results of this RMG in relation to the triple point of CO_2 at an international level at a conference and in a peer reviewed scientific publication.

The research activities within the task will be:

- **A3.1** - The RMG researcher will receive training from CNAM on the equipment, set up and measurement methods required for performing acoustic temperature measurements. There will also be training on the other equipment that will be used to determine the reproducibility and stability of the plateau, the self-heating, the heat flux, the hydrostatic head, the insulation leakage, the SPRT Pt oxidation and the gas pressure within the FPC. In addition, the RMG researcher will receive training on the construction of the CO_2 FPC and on performing uncertainty evaluations.
- **A3.2** - The RMG researcher will present the results during at least one international conference (e.g. European Conference on Thermophysical Properties 2023).
- **A3.3** - The RMG researcher will submit at least one paper, jointly authored by SMU and CNAM, to a peer-reviewed journal (e.g. International Journal of Thermophysics, Metrologia, etc.) within a few months of the end of the RMG.

C2 Task 4: Management

The aim of this task is to attend project meetings and provide a final report to EURAMET.

The activities within the task will be:

- **A4.1** - The RMG researcher will plan to attend at least one project meeting during the lifetime of the JRP.
- **A4.2** - The RMG researcher will write the final report on the RMG (in accordance with the EMPIR Reporting Guidelines – Part 8) summarising the technical work and impact activities. The RMG researcher will then submit this report to EURAMET as a final deliverable

Section D: Quality and efficiency of the implementation

D1 Description of RMG researcher

Peter Pavlasek is currently the lead researcher in the temperature department of the Slovak Institute of Metrology (SMU). He has more than five years of experience in the temperature field within this national metrology laboratory. His duties at SMU have consisted of SPRT and thermocouple calibrations, data analysis, and uncertainty evaluation connected with SPRT measurements and with the statistical analysis of data. He has been involved in several multilateral and bilateral comparisons within the temperature field that make use of fixed-point cells. He also has experience of international research in the contact temperature field during which he has been a guest researcher in leading EU national metrological institutions like LNE, CNAM, NPL, PTB and INRiM.

D2 Description of the employing organisation

The Slovak Institute of Metrology (SMU) was established by the UN MS SR (Superior body) Foundation charter. In accordance with the Slovak Act on Metrology No. 142/2000 and its Foundation charter, the basic role of the SMU is to be the main professional metrology body in the Slovak Republic. This includes the realisation of research and development in the field of metrology, the maintenance of national standards and participation in international comparisons of set standards, and the preservation of measuring units and their scales. Furthermore, SMU is responsible for the transfer of national standard values to other measuring instruments, or to accredited calibration laboratories. SMU is also involved in the approval and certification of reference materials, in providing international recognition of national standards, in the certification of reference standards and lastly they represent the Slovak Republic as the international metrological organisation. SMU as a National Metrological Institution is strongly interested in the upcoming evolution of the SI and the connected modifications of the temperature scale that the new definition of the temperature unit will bring. The knowledge and findings gained through this RMG will enable SMU to keep track of current developments in the field of primary temperature metrology.

D3 Description of the guestworking organisation

LNE, the French NMI, has a joint laboratory with CNAM. LNE-CNAM has the "Thermal Metrology" department which is responsible for the French national temperature standards. LNE-CNAM has world-leading capability for performing acoustic and contact temperature measurements in the temperature ranges required for the investigation of the CO_2 fixed point cell. LNE-CNAM has extensive experience and capabilities in fixed point cell creation, which will be crucial for this RMG. LNE-CNAM is capable of performing measurements of T-T90 by acoustic gas thermometry (AGT) in the temperature range needed for this RMG. LNE-CNAM has strong linkage with the world metrology community through representation on CCT, CCT-WG for contact and non-contact thermometry, on a number of CCT Task Groups, as well as active involvement in EURAMET TC-T technical committees. Finally, contributing staff are experienced in working on collaborative projects and have led work packages in successfully completed EMRP JRPs like IND01 HiTeMS, ENV07 MeteoMet, SIB01 InK, SIB10 NOTED etc.

Section E: Ethical issues

This RMG:

- will comply with national legislation, regulations and ethical rules in the countries where the project will be carried out. Where appropriate, participants will seek the approval of the relevant national or local ethics committees prior to the start of the project.
- will comply with the highest standards of research integrity (as set out in the European Code of Conduct for Research integrity).
- will take the necessary steps to protect the research and its results from abuse, if the research has the potential for 'Dual use' (military applications or malevolent/criminal/terrorist abuse).

Section F: Breakdown of the training & development allowance

Description	Related task	Approximate cost (€)
Participation in a conference (e.g. . European Conference on Thermophysical Properties 2023) in order to present the results of the RMG.	Task 3	1000
Participation in a JRP meeting in order to present the results of the RMG.	Task 4	500
Total Max for RMG = 1500 € every 6 months FTE		1500

EMPIR Researcher Mobility Grant Contract
Annex 2 – Payment Schedule

RMG Grant Reference:	18SIB02-RMG2
Parent Project:	18SIB02
Researcher:	Peter Pavlasek
Country of Guestworking:	France
Country Correction Coefficient applied:	1.11
Total Value of EMPIR RMG Grant:	€ 10,492.00
Version Date:	29-Jun-21

Period (months):	Initial Payment	Final 15%	Total
Living Allowance (€)*:	7,992.00		7,992.00
Family Allowance (€)*:	0.00		0.00
Development Allowance (€):	1,500.00		1,500.00
Travel Allowance (€):	1,000.00		1,000.00
Final Payment (€):	-1,573.80	1,573.80	
Total Payment Request (€):	**8,918.20**	**1,573.80**	**10,492.00**

* adjusted by Country Correction Coefficient