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The Euromet Project 772 on the Temperature Amplifier, from Its Proposal to the Present Status

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Abstract In February 2004, a Euromet project was discussed and an agreement was proposed among nine European national metrology institutes. The project is aimed at investigating the use of the Temperature Amplifier as a new temperature standard in the field of platinum resistance thermometry between the fixed points of Al and Ag. Since that time, several systems and devices have been studied, developed, manufactured, and assembled at INRiM. New gas-controlled heat pipes were manufactured taking into account the experience with devices acquired in previous years. An innovative pressure controller was studied and built for the purpose; the relevant electronic components were developed and fabricated by INRiM. Dedicated furnaces were designed and assembled, together with all the proper cooling lines. Control and acquisition software was also developed at INRiM. Some of those components have been tested and characterized both at the Italian (INRiM) and the French (LNE-INM/CNAM) Institutes of Metrology. This article describes the innovative devices dedicated to this project together with the first test results. The main results are also summarized, together with the descriptions of the plans for future project advances that will involve the other participating institutes.

Keywords Cooperation agreement · Euromet · Research project · Resistance thermometry · Temperature scales

1 Introduction

Despite the possible new definition of the unit of temperature (the kelvin), the International Temperature Scale (ITS) will continue to be the subject of ongoing improvement

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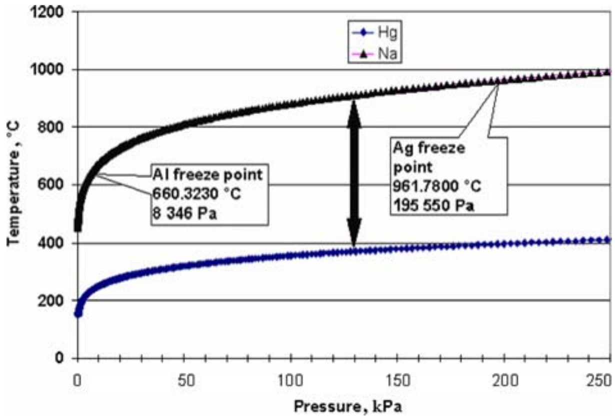

Fig. 1 Mercury and sodium vapor-pressure curves. Arrow indicates that at the same pressure one mercury temperature corresponds to a single sodium higher-temperature value. Controller and system work well in the pressure range corresponding to sodium temperatures including the aluminum and silver freeze points

and studies. We expect the ITS, through the "mise en pratique" for the realization of the unit, to be open to new definitions for specific fields of interest. At present, since no reference temperatures are defined between the fixed points of aluminum and silver, corresponding to the wide interval between 660 and 962°C, studies are currently underway with the aim of proposing a new temperature standard in this range.

Recent studies [1] at IMGC (now INRiM) evidenced good agreement between the immersion characteristics in a mercury-filled gas-controlled heat pipe (GCHP) and the Clausius–Clapeyron profile. This result led to the idea of using coupled GCHPs to thermodynamically relate two different temperature ranges, with the possibility of redefining one temperature range in terms of another: this is the "Temperature Amplifier" (TA). The ITS can therefore be defined in a new way: any accurate, reproducible temperature range may be used to generate another temperature interval, ranging between 660 and 962°C, the relationship between the two ranges being thermodynamically related by the two pure substances used for the vapor–liquid transitions.

Given that two GCHPs connected to the same pressure line are thus operating at the same pressure, the lower temperature of the liquid/vapor transition in the first GCHP corresponds to one and only one higher temperature in the second GCHP, as indicated in Fig. 1. If the second GCHP has sodium as the working fluid, in the pressure range between 5 and 200 kPa, the liquid–vapor equilibrium temperatures cover the range between the Al and Ag fixed-point temperatures. The reproducibility and stability of the GCHPs at high temperature can be used to overcome the well-known ITS-90 non-uniqueness of high-temperature standard platinum resistance thermometers (HTSPRTs) and their lack of stability. Vapor-pressure scales can also be proposed as a practical approximation of the ITS and for the calibration of SPRTs and thermocouples.

2 Euromet Project

Preliminary results for a new temperature standard between the Al and Ag fixed points have been published since 2002 [2–4]. Those results were discussed in several meetings and personal communications following their publication, and in February 2004 an agreement was proposed among the following nine European National Institutes of Metrology:

– the Italian Istituto Nazionale di Ricerca Metrologica (INRiM), coordinator of the project and task leader
– the French Laboratoire National de Metrologie et d'Essais—Institut de Metrologie (LNE-INM/CNAM), task leader
– the British National Physical Laboratory Management Ltd. (NPL)
– the Portugese Instituto Portugues da Qualidade (IPQ)
– the Turkish Ulusal Metroloji Enstitusu (UME)
– the Spanish Centro Espanol de Metrologia (CEM)
– the Nederlands Meetinstituut (NMi)
– the Swiss Federal Office Of Metrology (METAS)
– the Hungarian Trade Licensing Office (MKEH, formerly OMH).

At the TEMPMEKO 2004 meeting, several articles discussed the TA [5] and studies of new GCHPs [6], as did one of the plenary sessions [7]. Euromet 772 started shortly thereafter.

The first steps of the project were devoted to the construction of a totally new system with respect to the apparatus used for the first studies. The TA used for the measurements since 2002 was quite a complicated system that involved two or more computers, two or even three bridges, a complex pressure line and engines, photo-sensors, and several gauges and instruments for its control. Moreover, the GCHPs were manufactured by the Joint Research Centre (JRC) of Ispra and are no longer available. The first tasks of the project were concentrated on two subjects: the construction of new GCHPs and the realization of a new pressure control system.

The INRiM activities started immediately after June 2004. A new prototype pressure controller [8], expressly dedicated to the TA, was studied, designed, and assembled. This pressure controller is equipped with a series of electrovalves that connect the two heat pipes to several volumes with a pressure intermediate between vacuum and the pressure of a helium reservoir. Pressure inside the GCHPs can therefore be controlled with a sensitivity of 1 ppm by activating the electrovalves. Dedicated electronics were also designed and assembled. Several circuits and microprocessors are in continuous communication in order to allow the required connection between the electrovalves, a pressure gauge, and a resistance bridge. This innovative pressure controller uses a SPRT as the "pressure sensor"; due to the thermodynamic relationship that links the temperature and the pressure of a boiling fluid, it is possible to control a pressure set point through the corresponding temperature value. In this way, advantage is taken of the very high sensitivity and reproducibility of a SPRT, which translates into pressure sensitivity and stability that is much higher than that obtainable with any commercial pressure gauge. The specific software required for such an innovative approach to pressure control was developed at INRiM. The pressure controller and its dedicated software have been realized for both INRiM and LNE-INM/CNAM GCHPs.

The manufacturing of the new GCHPs started at INRiM in 2005 and dedicated furnaces were also designed. In the first months of activities, almost everything necessary for the realization of the TA prototype was taken into account, the construction of the parts started, and many were completed. The design of the new heat pipes is an improvement over that of the heat pipes manufactured some years ago at JRC and takes into account all recent studies carried out at IMGC on these devices. Inconel heat pipes are now available with either potassium or sodium as working fluids for high-temperature measurements. Stainless steel heat pipes have also been manufactured, to be filled with low-temperature working fluids, such as mercury. Six-well and three-well pipes are available, both for higher or lower temperature, on request. The GCHPs are equipped with dedicated new furnaces, new power-control systems, and cooling lines. Two or more GCHPs can be connected to the same pressure-controlled line in order to realize both the TA and to obtain continuous temperature ranges for thermometer calibration, from 200 to 1,000°C.

3 2006 Progress

Most of the activities of the second year of the project were carried out at IMGC (now INRiM) in a new laboratory [9] devoted to the TA project and to GCHP studies and applications, where all the equipment is housed, assembled, and characterized. All the furnaces dedicated and purposely designed for the two new GCHPs were manufactured and tested. A new power-controlling system based on the innovative principle of evaluating the physical position (height) of the working fluid vapor interface with the controlling gas was also checked and demonstrated to be an accurate way to control the stability of the power used to feed the GCHP and to maintain the vapor/liquid phase transition inside it, with the SPRT sensing element always in the same immersion conditions. Cooling lines were also manufactured to cool the GCHP chimneys, the thermometer well tops, and the furnaces. The realization of the new pressure controller specially developed as the temperature/pressure controlling unit for the GCHPs was completed and the device tested. The controlling software was also developed and all the processes were carefully characterized. The controlling system was connected to a mercury-filled GCHP that was previously operated with an experimental pressure controller. The capabilities of the pressure controller and the software were tested under various conditions.

The pressure controller was then brought to CNAM, in Paris, where it was connected to a methanol-filled GCHP. The controlling procedures were set and all the parameters evaluated for this application. The system was demonstrated to be flexible and operated well. Back at INRiM, a new GCHP, one of the two new ones that are dedicated to the TA, was filled with 99.99999% pure mercury. The new GCHP was turned on and a characterization campaign started to evaluate the temperature uniformity and stability under fine pressure control using the new controller. This GCHP will be used as a low-temperature reference and controller for the TA [10].

4 Final Assembly of the Temperature Amplifier

In late 2006, a second GCHP of Inconel provided with six thermometer wells was filled with sodium, connected to the same pressure line where the previous mercury GCHP was connected, and characterized. Further control of helium leakages was performed for the whole pressure line. The devices involved in the final assembly of the TA are:

– New pressure controller
– ASL F18 Bridge and switchbox unit
– PC (acquisition and control)
– Heaters
– Power line
– Coolers
– Pressure line
– Mercury GCHP (three wells, stainless steel)
– Sodium GCHP (six wells, Inconel)
– 25 Ω SPRTs
– 2.5 Ω HTSPRTs

A series of measurements were performed with only the sodium GCHP in order to check its correct operating conditions and to preview its capabilities. The two GCHPs were then connected to the same helium line, controlled by means of the same pressure controller, and finally turned on. Then, starting from a low pressure below 1 kPa, the measurements started. In January 2007, two researchers from NIM joined the work at INRiM as part of a cooperation agreement between the two institutes [11]. The two researchers were employed to evaluate the amplification curve. This new determination covers a wider range with respect to the previous one, ranging from less than 1 kPa up to 250 kPa. Measurements will also be fundamental to evaluate the correct power distributions and the best capabilities of the GCHPs. At the end of those measurements, the new TA will be totally characterized and will be ready to be used with several other SPRTs and HTSPRTs.

5 772 Becomes a Proposed iMERA+ JRP

Like some other Euromet projects, 772 became a proposed iMERA+ JRP in 2007, at first coded JRP9 for the first of the four Targeted Programme areas, the TP1 on "SI and Fundamental." At first, the same partners remained involved and a cooperation agreement was signed. After this first step, several institutes had to declare their "Expression of Interests" (EOIs); some of the partners included the "TA" in their EOIs. The next step involved writing, again, a new Joint Research Proposal (JRP), taking into account the declared EOIs. The 772 project finally became TP1 JRP 3.4 on the "*mise en pratique* of the kelvin between the Al and Ag fixed points." The project is structured through five tasks, some of which are led and coled by INRiM and the Spanish CEM, which declared special interest in the mercury vapor-pressure curve evaluation, and its dependence on the isotopic composition and impurities. The original project has been simplified and the circulation of the complete device has been substituted with the in situ comparison of SPRTs and HTSPRTs.

While re-writing the project as KRP9, other partners joined: Instituto Geológico y Minero de España (IGME, ES), Universidad de Oviedo (UniOv, ES), and Politecnico di Torino (PoliTo, IT). The NMIs involved will follow the realization of the TA and will send their SPRTs and HTSPRTs to INRiM and/or LNE-INM/CNAM. The PoliTo will be involved in the exploitation, dissemination, and knowledge transfer, while the Spanish IGME and UniOv will contribute to the research regarding mercury vapor analysis. The relevant capabilities of each institution useful to this project are reported in Table 1.

Researchers can go directly to the laboratories where the TA will be operative and make temperature measurements with their SPRTs, in order to evaluate the Temperature Amplification curve and the GCHP performance in terms of temperature uniformity and stability over the whole temperature range. INRiM will collect all the data and maintain close contact with all the laboratories, in order to help with the measurements and any troubleshooting. Measurements will also be performed to evaluate the capabilities of the GCHPs as calibration devices.

A summary of the work packages is reported in Table 2, while the deliverables list is detailed in Table 3.

Table 1 Relevant capabilities of each institution for the JRP

Institution	Relevant capabilities for this JRP
INRiM	Heat pipe manufacturing and filling. Specific electronics design and assembly. Software realization and validation. Pressure and temperature measurements by means of primary standards
CEM	Mercury distillation. Thermophysical properties analysis
IPQ	Mathematical models for data treatment. Thermal measurements
LNE-INM	GCHP use and comparison with primary fixed points
Polito	GCHPs used as calibration facilities. Knowledge transfer to industries and calibration services
IGME	Mercury impurities analysis
UniOv	Use of stable isotopes and isotope ratios in chemical metrology

Table 2 Work packages of the iMERA+ JRP 9

WP	Work package name	Active partners
WP1	JRP Management and coordination	*CEM*, INRIM, *LNE-INM*, *IPQ*
WP2	Proposal of a new temperature standard between 660 and 960°C. Temperature Amplifier realization and use. Measurements and data evaluation.	INRIM, *LNE-INM/CNAM*, *IPQ*
WP3	Mercury vapor-pressure curve measurements: impurities and isotopic composition influence.	CEM, *INRIM*, *UniOv*, *IGME*
WP4	Capabilities of the gas-controlled heat pipes as devices for calibrations of industrial thermometers and thermocouples.	INRIM, *LNE-INM*, *IPQ*, *PoliTo*
WP5	IMPACT: exploitation, dissemination, and knowledge transfer	INRIM, *all funded and cofunding partners*

Table 3 Deliverables

WP	Del. N.	Deliverable description	Lead partner	Other partners	Delivery date month
1	1.1	Report of the kick-off meeting	INRIM	CEM, IPQ	Month 3
1	1.2	Annual reports	INRIM	CEM, IPQ, LNE-INM	Annually
1	1.3	Final report	INRIM	All partners	Project end
2	2.1	A new working prototype of TA	INRiM		18
2	2.2	Capabilities of a proposed new temperature standard with respect to the existing one.	LNE-INM	CEM, INRiM , IPQ	24
2	2.3	Mathematical model for a new temperature standard between 660 and 960°C	IPQ	CEM, INRiM	30
3	3.1	A new, more accurate, determination of the mercury liquid–vapor phase-transition curve between 400 Pa and 400 kPa	INRiM	CEM, IPQ	9
3	3.2	A thermo-physical model of the isotopic composition and impurities effect on the liquid–vapor phase-transition curve of mercury between 400 Pa and 400 kPa	CEM	INRiM, UniOv, IGME	36
3	3.3	A new value of the mercury boiling point, determined with reduced uncertainty with respect to the published one, to be included in the CODATA	INRiM	CEM	30
4	4.1	A new device for thermometer and thermocouple calibration from 40 to 150°C	LNE-INM	INRiM	30
4	4.2	A new device for thermometer and thermocouple calibration from 150 to 450°C	PoliTo	INRiM	30
4	4.3	A new device for thermometer and thermocouple calibration from 450 to 950°C	INRiM	LNE-INM/CNAM	30
4	4.4	A new pressure controller for pressure sensor calibration between 400 Pa and 400 kPa	INRiM		9
5	5.1	Adoption of the Na liquid–vapor phase-transition curve as a new temperature standard between the Al and Ag fixed points recommended to CCT	INRiM	All partners	35

Table 3 continued

WP	Del. N.	Deliverable description	Lead partner	Other partners	Delivery date month
5	5.2	New values for the mercury vapor-pressure curve between 400 Pa and 400 kPa with lower uncertainties	INRiM	All partners	12
5	5.3	Characterization and proposal of new devices for industrial thermometer calibration with reduced uncertainties with respect to the instruments commercially available	INRiM	All partners	30
5	5.4	Proposal of the use of new special devices for the study of phase transitions and thermophysical properties of elements and compounds	INRiM	All partners	30

6 Conclusions

The capabilities of the new GCHPs, of the new pressure controller, and of the whole Temperature Amplification system will be evaluated together with the realization of further TAs. The device will then be proposed as a new temperature standard and/or as a calibration facility. The proposal for a practical realization of the ITS by means of vapor-pressure curves in different temperature ranges will be evaluated. A complete report describing all the phases of the project, from the assembly of the prototype to the analysis of the collected data, will be available at the end of the project, in 2009.

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