Publishable Summary for 15RPT03 HUMEA
Expansion of European research capabilities in humidity measurement

Overview

The control and measurement of humidity is important for many industrial applications and to ensure the appropriate storage of materials and products. The overall objective of this project was to develop or extend the measurement and research capabilities of the participating emerging NMI/DIs' countries in the field of humidity measurements via the development and characterisation of an inner chamber for calibration of relative humidity instruments and a systematic review and improvement of dew point generators. The extent of improvements was designed to meet stakeholder needs, with an optimised effort to avoid duplication of resources. Individual strategies for humidity metrology development have been prepared by the emerging NMI/DIs and then discussed within the EURAMET community, ensuring a coordinated and optimised approach.

Need

Humidity is a vital parameter in the control of indoor climate and ventilation, the storage of food products, industrial and medical gases, textile, paper and many other products. Humidity affects many properties of air, and of materials in contact with air. Water vapour is a key agent in both weather and climate, and it is a key atmospheric greenhouse gas. Air-conditioning systems in buildings often control humidity, and significant energy may go into cooling the air to remove water vapour. Humidity measurements contribute both to achieving correct environmental conditions and to minimising the energy cost of this. A huge variety of manufacturing, storage and testing processes are humidity-critical. Humidity measurements are used wherever there is a need to prevent condensation, corrosion, mould, warping or other spoilage of products. Air humidity is also a crucial parameter due to the enormous heat capacity of gaseous water and its key role in atmospheric processes. Traceable measurements of air humidity from the ground level up to the stratosphere are required. Numerous energy technologies – established and novel – need reliable humidity measurements in a range of gases, at a range of pressures.

Prior to the start of the project, the development of humidity sensors and apparatus had matured to a level where traceable calibration was beneficial to all industries in which humidity and moisture measurement and control are important. Measurement of humidity is complex and vitally important to a huge range of industries, as well as in healthcare and in terms of climate change and global warming.

The NMI/DIs in the consortium often received feedback from their clients, indicating a desire for improved uncertainties in humidity measurement. Due to the tightness of manufacturer's specifications and the difficulty in achieving the uncertainties necessary to verify these specifications, there was an urgent need to improve the uncertainty of relative humidity and dew point measurements in most emerging NMI/DIs.

Establishing the infrastructure for humidity measurements, assuring traceability and providing dissemination are important concepts in both developed and emerging NMI/DIs as well as a precondition to related research, industrial applications and quality standards and support for various services, including the grand challenges (health, environment and energy) and closely associated with quality of life measures and implementation of specific EU legislation.

Objectives

The overall objective of this project was to develop or extend the measurement and research capabilities of the participating emerging NMI/DIs' countries in the field of humidity measurements.

The specific scientific and technical objectives of this project were:

1. To identify existing and future needs in the field of humidity measurement in the participating emerging NMI/DIs' countries.
2. To improve measurement methods in the field of humidity via the development and characterisation of an inner chamber for calibration of relative humidity instruments. The target uncertainties are between 0.3 %rh and 2 %rh for a relative humidity range of 2 %rh to 95 %rh at temperatures from -60 °C to 100 °C. To implement the improved relative humidity capability into the national/regional traceability infrastructure.
3. To organise and undertake an intercomparison of relative humidity measurements using the small chamber to underpin and validate the procedures developed and measurement capabilities of the participants.
4. To improve research capacity in the field of dew point measurements by systematic review and improvement of dew point generators. The target uncertainties are between 0.05 °C and 0.1 °C for a temperature range of -70 °C to 90 °C. To implement the improved dewpoint capability into the national/regional traceability infrastructure.
5. To develop individual strategies for the long-term development of research capabilities in humidity traceability including a strategy for offering calibration services from the facilities established to customers in their own country and neighbouring countries, through questionnaires and workshops organised in the local language, which will involve the broadest spectrum of stakeholders. The individual strategies will be discussed within the consortium and will lead to an overall strategy document to be presented to the EURAMET TC-T, to ensure that a coordinated and optimised approach to the development of traceability in this field is developed for Europe as a whole.

Progress beyond the state of the art

Through this project a chamber within a chamber system for the calibration of relative humidity instruments. was designed, constructed and characterised. The smaller chamber led to reduced spatial variation of the parameters (temperature, humidity etc.), a more rapid stabilisation of the conditions within the chamber, and therefore a faster turnaround time for calibrations. An intercomparison of relative humidity measurements using the small chamber was carried out to underpin and validate the procedures and measurement capabilities of participants developed during the project.

The project addressed research capacity in the field of dew point measurements by the undertaking of a systematic review and improvement of dew point generators at each of the emerging NMI/DIs. This established a methodological approach for building new dew point generators and for allowing development of traceability in dew point measurements in these countries.

This improved capabilities in the measurement of humidity and therefore the quality of calibration services for industrial and research stakeholders was also improved.

Results

Identification of existing and future needs in the field of humidity measurement

The needs related to relative humidity and dew point measurements in the emerging countries were identified through engagement with the stakeholders.

Two surveys were performed, the first one to collect data about the measurement setups and capabilities in each of the project partners' laboratories and the second one to identify the stakeholders' needs. The surveys were conducted through questionnaires and the data collected was analysed and used as the basis for an assessment of the needs for relative humidity and dew point measurements in the partners' countries. These identified needs were then considered throughout the rest of the project's activities, including defining the scope of the training organised for partners and stakeholders in participating countries. The first training course for consortium members and interested parties was held in Ljubljana on the 24th and 25th January 2017. Afterwards, training sessions and workshops for stakeholders were also organised in Italy, Ireland, Bosnia and Herzegovina, Serbia and Croatia.

Improvement of measurement methods via the development and characterisation of an inner chamber for calibration of relative humidity instruments

After determining the existing capabilities at each member institute, the consortium designed an inner chamber for the calibration of relative humidity instruments (new RH chamber) intended for use in combination with the climatic chambers already existing in humidity laboratories. The primary assumption was that the new RH chamber would provide a calibration environment of higher stability and lower temperature gradients in comparison to the existing climatic chambers, leading to an improvement in corresponding calibration uncertainties. Since a variety of climatic chambers were in use for the calibration of RH instruments, the consortium adopted a modular design for the new RH chamber. In this way, the new RH chamber could be fitted and used inside climatic chambers of different shapes and working volumes. Considering the identified needs for relative humidity measurements in the partners' countries, the new RH chamber was designed for a relative humidity range of 2 %rh to 95 %rh at temperatures from -60 °C to 100 °C.

The new RH chamber was manufactured in Italy, where the preliminary performance evaluation was also carried out. In this research, the process of designing, producing and characterising the calibration sub-chamber was studied. Experimental work was also carried out on a copy of the new RH chamber to gain practical knowledge and to learn and apply good practices and methodologies to the future characterisations. The initial characterisations were performed with the new RH chamber accommodated inside two climatic chambers, in the temperature range from 1 °C to 70 °C. The results indicated a significant reduction of temperature gradients and related measurement uncertainties in 11 of 14 measurements (improvements are between 400 % and 2400 %; 1000 % on average). At two measurements, improvements were moderate (approx. 50 %). At one measurement, the standard uncertainty was increased from 4.4 mK to 8 mK. Besides the determination of temperature gradients, characterisation at INRIM covered determination of temperature stability, pressure drop and purging time. The experiences in setting up and using the new RH chamber, gained through preliminary investigations, were shared with project partners at a workshop held at INRIM. A characterisation protocol was prepared, and related measurements performed at INRIM, IMBIH, DMDM, NSAI, ME-BOM, MER, UL and FSB. The considered parameters were temperature stability, inhomogeneity and dew/frost point stability inside the working volume of the existing climatic chambers and the new RH chamber. The chamber was characterised through 28 measurements, in the range from -60 °C to 100 °C. Improvements were achieved at 26 measurements, ranging from 3 % to 1003 %. The corresponding standard uncertainties, for calibration of relative humidity instruments in the range from 2 %rh to 95 %rh, are between 0.003 %rh and 1.38 %rh. In two laboratories, the new RH chamber enabled extension of the temperature range for calibration of relative humidity instruments.

Organisation of an intercomparison of relative humidity measurements using the new RH chamber

An interlaboratory comparison in the field of relative humidity measurements was organised to determine the degree of equivalence among the partners as well as for the verification of the overall improvements achieved through participation in this project. The intercomparison covered the relative humidity range from 10 %rh to 95 %rh at gas temperatures from -10 °C to 50 °C. Although the intercomparison was initially planned only among the project partners, in order to increase the project impact, it was decided to extend it to include EIM - Greece and JV - Norway. Following the production of the new RH chamber and the dissemination workshop at INRIM, two sets of transfer standards were obtained from Rotronic UK and Alius grupa d.o.o. The intercomparison protocol was then prepared and submitted to the EURAMET TC-T chair after which it was registered at EURAMET under registration no. 1442. All the participants finished the intercomparison measurements using the new RH chamber. Analysis of the intercomparison results showed a good agreement among the participants, confirming at the same time the improved uncertainties achieved by using a new RH chamber. It is worth mentioning that seven of the12 participants in this intercomparison do not have CMC values for calibration of relative humidity sensors published in the BIPM key comparison database (FSB, CMI, ME-BOM, MeER JV, DMDM and TUBITAK) and that this intercomparison covers a temperature range which is wider than the ranges published in the KCDB for IMBIH (20 °C to 24 °C), UL (-10 °C to 20 °C), NSAI (5 °C to 60 °C) and EIM (10 °C to 70 °C). Therefore, the results from this intercomparison are valuable to almost all the participants as supporting evidence for the submission of new or improved CMC claims to BIPM for publication in the KCDB. for two of the laboratories, this was their first participation in an intercomparison registered at EURAMET in the field of relative humidity measurements.

Improvements in the field of dew point measurements by improving dew point generators

A survey regarding dew point measurements was performed to find out the needs and requirements of stakeholders and the capability of the partners. The results enabled optimal solutions for dew point setups to be suggested for each individual partner, according to the needs of their national stakeholders. By carrying out a systematic review, modifying factors of influence, such as flow rate, pressure, temperature range, bath performance and tubing type, technical documentation on how to improve the respective measurement uncertainties was prepared. The target uncertainties were between 0.05 °C and 0.1 °C for a temperature range of -70 °C to 90 °C. Each participating emerging NMI/DI implemented and tested the designed solutions at their laboratory with their equipment, achieving improvements as given in the following table:

NMI/DI	**Improvements Dew-point measurements**	
	Temperature range, °C	Uncertainty, °C
IMBiH	Expanded scope: -50 to 40	0.09 to 0.016
MER	10 to 70	0.39 to 0.50
NSAI	Expanded scope: -45 to 90	0.06 to 0.04
DMDM	Expanded scope: -20 to 40	0.1
ME-BoM	Expanded scope: -50 to 70	-
FSB	-70 to -34 -34 to 55 55 to 65	0.042 to 0.1 0.024 to 0.037 0.062 to 0.07

Development of individual strategies for the long-term development of research capabilities in humidity traceability

An overview of the experienced partners' individual strategy documents in metrology or the humidity subfield was presented at the beginning of the project. This led to the development of a draft template for individual long-term strategy documents for the participating emerging countries.

Individual strategy documents for humidity research and development of the associated capabilities in Serbia, Bosnia and Herzegovina, Montenegro, Ireland, North Macedonia, and Croatia have been prepared and adopted by the respective NMIs.

Each individual strategy document proposes a long term strategy, over the next five to 15 years, taking into account future humidity measurement capability requirements and the need for developments linked with environmental, health and energy topics.

The individual strategy documents have been summarised in a single strategy document, which reports an overview of future requirements and developments in the humidity subfield for NMI/DIs from emerging countries. The strategy document was prepared within the scope of regional coordination with the aim of promoting small specialisations, taking care to avoid duplication of humidity resources. The strategy document was promoted through presentations at international conferences, such as Tempmeko 2019.

Impact

A project website was created and updated regularly with news of the project, along with an associated LinkedIn profile.

A training course in humidity was held for consortium members and interested parties in January 2017. This course covered all aspects of humidity measurement and allowed for extensive discussion of the regional measurement requirements and capabilities. The training had a significant impact on the knowledge of each consortium member.

The second training course was held for consortium members in October 2017. The focus was on the installation, set-up, and fine tuning of the chamber within a chamber system for humidity measurements. During the meeting, the inner chamber characterisation protocol was presented and discussed by the partners. The final version of this document was prepared following separate characterisation of the chamber in each partner country when the inner chamber was circulated in 2018.

A stakeholder training working group was set up by the consortium members with the aim of preparing training material to assist in training of stakeholders within each member region. The material includes a course overview, presentation slides and exercises to be carried out by attendees to improve their understanding of humidity measurement. All material is available for delivery by partners in their respective regions.

Stakeholder workshops were held in the partner countries, using the materials prepared by the working group. Feedback was unanimously positive, and will guide future research in the field of humidity among the partners.

Impact on industrial and other user communities

The small chamber within a chamber approach should reduce the time needed for a calibration and so will increase the time that each instrument is available to the owner for measurements at their facility, reducing operation and maintenance costs.

Through the development of training courses in humidity measurement, the outcomes of the project, as well as general humidity measurement training have been delivered effectively to industrial stakeholders, thereby improving understanding and skills among industry within the European Union.

Through the development of best practice guides in the fields of Relative Humidity and Dew-point measurement, a standardised approach has been made available to end users throughout Europe, as well as an improved understanding of the most appropriate measurement techniques and sources of error associated with each field.

In the area of relative humidity and dew point measurement, knowledge transfer from experienced NMI/DIs to those less experienced in how to use new types of humidity instruments and facilities has been very beneficial. It has helped to raise the knowledge, measurement and research capabilities and is promoting consistency within humidity metrology.

Through highlighting the importance of humidity to processes, and to human comfort levels, the results of this project will lead to a better understanding of humidity among stakeholders and therefore to an improvement of environments with climate control, as well as humidity or moisture dependant industrial processes. A better understanding of humidity measurement and control will also allow the development of optimal storage conditions for produce, leading to a reduction in waste and spoilage throughout Europe.

Impact on the metrology and scientific communities

The validated calibration techniques and associated uncertainty formulation developed in the project at emerging NMI/DIs will be used directly by calibration laboratories, which will assure traceability of measurements performed using different humidity sensors. Measurement results will be reported with the associated measurement uncertainty, which will enable their transparent comparison and comparison of the performance of various humidity sensors. Dissemination of traceability amongst NMI/DIs will provide access to improved capabilities for national and accredited laboratories and support consistency in measurement capabilities. Harmonised and traceable calibration, usually based on accreditation, is a basic requirement for mutual recognition of calibration results, offering a cost saving to European exporters. The recognised traceability of calibration results will also provide an important contribution to consumer protection.

The RMG researchers' work will bring increased technical skills in the humidity fields and also increasing capacity in research in their countries, it is a good opportunity for further growth and development of NMIs.

The improved capabilities developed at the participating laboratories will result in better uncertainties in the calibration of humidity instrumentation and hence will provide customers with a clearer picture of how their equipment is performing year on year thereby allowing better control of their processes.

Impact on relevant standards

By identifying relevant standards which involve humidity measurements, it will be possible to determine the range and accuracy requirements which would permit industry to comply with these standards. Where the humidity measurement expectations are considered unachievable or unrealistic by the consortium, this information will be communicated to the relevant standards committee with a view to influencing future drafts of the standards.

IEC TC 82, CEN, TC 346, IEC TC 47 and IEC TC 50 were identified as the most relevant Technical committees to this project. These committees were contacted and informed of the aims of the project. Once the results and conclusions were compiled, these were sent to the convenors for dissemination among the committee members. This has led to expressions of interest in future research from the committees, as well as an invitation for the partners to join the technical committees and actively participate in the development and improvement of standards in future. Where deemed relevant, the results will be considered when compiling future drafts of the standards.

Longer-term economic, social and environmental impacts

Establishing traceable measurements in humidity at the level needed by each participating country will enable important inputs for areas of research, innovation and patenting in this field in future EMPIR projects. An important aspect of this project is the collaboration of less experienced NMI/DIs with experienced NMI/DIs. The upgraded skills and expertise in emerging countries' NMI/DIs will be applicable to industrial purposes, and the development of practical tools in the form of guidelines and procedures for enhancing the transfer of new capabilities to end-users is also expected.

Through highlighting the importance of humidity to processes, and to human comfort levels, this project will lead to a better understanding of humidity among stakeholders and therefore to an improvement of environments with climate control, as well as humidity or moisture dependant industrial processes. A better understanding of humidity measurement and control will also allow the development of optimal storage conditions for produce, leading to a reduction in waste and spoilage throughout Europe. Following the long term strategy by each partnering country gives better economic, social and environmental impact, also.

List of publications

1. *Expansion of European research capabilities in humidity measurement*, N. Hodžić, S. Čohodarević, N. Jandrić, R. Strnad, D. Sestan, D. Zvizdic, V. Fernicola, D. Smorgon, L. Iacomini, S. Simic, D. Mac Lochlainn, N. Karaböce, S. Oğuz Aytekin, J. Bojkovski8., D. Hudoklin, O. Petrušova and T. Vukicevic, 18th International Congress of Metrology (2017) 06006, http://dx.doi.org/10.1051/metrology/201706006
2. *Improving emerging European NMIs' capabilities in humidity measurement*, N. Hodžić, S. Čohodarević, N. Jandrić, R. Strnad, D. Zvizdić, D. Šestan, V. Fernicola, D. Smorgon, L. Iacomini, S. Simić, D. Mac Lochlainn, N. Karaboce, S. Oguz Aytekin, J. Bojkovski, D. Hudoklin, O. Petrušova and T. Vukičević, Journal of Physics: Conf. Series 1065 (2018) 122019, http://dx.doi.org/10.1088/1742-6596/1065/12/122019
3. *Development and preliminary investigation of a modular chamber for calibration of relative humidity instruments*, D. Šestan, D Smorgon, P. Rothmund, L. Iacomini, K. Šariri, V. Fernicola, D. Zvizdić and N. Hodžić, Journal of Physics: Conf. Series 1065 (2018) 122017, http://dx.doi.org/10.1088/1742-6596/1065/12/122017

<table>
<tr><td colspan="2">Project start date and duration:</td><td>01 June 2016, 36 months</td></tr>
<tr><td colspan="3">Coordinator: Nedzadeta Hodzic, IMBiH Tel: +38 733568928 E-mail: nedzadeta.hodzic@met.gov.ba
Project website address: http://www.humea-empir.org/</td></tr>
<tr><td>Internal Funded Partners:
1. IMBiH, Bosnia and Herzegovina
2. CMI, Czech Republic
3. FSB, Croatia
4. INRIM, Italy
5. DMDM, Serbia
6. NSAI, Ireland
7. TUBITAK, Turkey
8. UL, Slovenia</td><td>External Funded Partners:
9. ME-BoM, North Macedonia
10. MER, Montenegro</td><td>Unfunded Partners:</td></tr>
<tr><td colspan="3">RMG1: JV, Norway (Employing organisation); INRIM, Italy (Guestworking organisation)
RMG2: DPM, Albania (Employing organisation); CMI, Czech Republic (Guestworking organisation)</td></tr>
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