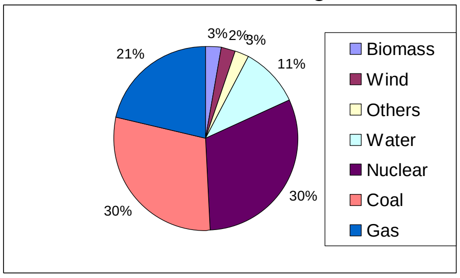
Final Publishable JRP Summary Report for JRP ENG06 Power Plants "Metrology for improved power plant efficiency"

Overview:
Large scale power plants based on nuclear or conventional fuel provide about 80 % of generated electricity in the EU and nearly 90 % of hot water used for district heating.



Electricity generation by fuel used in power plants, EU-27, 2006
(% of total, based on GWh)

Despite the important and necessary increase of renewable energy by approximately 10% (year 2020), large scale power plants will form the backbone for the secure supply of energy for the next decades. It is evident, that improving the energy efficiency of nuclear, coal and gas plants will generate a significant contribution to energy conservation, preservation of natural resources, reduction of emissions and protection of environment.

Need for the project
The project focused on the one hand on metrological research that will reduce the measurement uncertainty of the important control parameters (temperature, flow, thermal energy and electrical output) of the power plants and on the other hand on researching advanced materials used in future turbines. The total results of the research work will allow for an overall additional enhancement of energy efficiency of 2-3 % for all types of large power plants, and therefore will result in comparable amount of reduction of emissions.

Scientific and technical objectives:
Efficiency enhancement by reduction of the uncertainty of the main control parameters is directly reflected by the scientific objectives:

1. Temperature measurement:
   - Develop an understanding of the major sources of uncertainty and draft of industrial resistance thermometers (up to 700 °C) in order to provide manufacturers with the knowledge to develop the improved thermometers required for next generation steam power plants
   - Develop a non-contact method based on radiation thermometry for surface temperature measurements of turbine blades (up to 1500 °C)
2. Thermophysical properties:
   - Develop or improve reference facilities and methods for the measurement of thermal properties (thermal diffusivity, emissivity and specific heat) of homogeneous solid materials and thermal barrier coatings (TBCs) at high temperature (up to 1500 °C)
   - Use the facilities and methods to investigate Ni-base alloys and/or TBCs under the temperature conditions encountered in gas turbines
3. Flow measurements:

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- Accurately characterise flow meters and flow velocity profiles in order to develop an extrapolation model that will enable flow meters to achieve an uncertainty of 0.5% in power plant applications

4. Electricity measurement:
   - Develop a fast, reliable and accurate (traceable) on-site measurements of the electrical output of power plants up to 200 MW at high voltage (100 kV) with an uncertainty of better than 0.1 %.

Results:

Objective 1: Temperature measurements

The project addressed both contact and non-contact thermometry in order to improve temperature measurement capabilities in conditions relevant to power plant operation.

In the field of contact thermometry for steam power plants, the project has provided great insight for the manufacturers of Pt thin film sensors and thermometers, leading to a reduction of the measurement uncertainty for temperature measurement in steam power plants from 8 K to 3 K at temperatures up to 700 °C. Furthermore the vibration data gathered allows better determination of the real mechanical load a thermometer has to endure in a power plant. The unique experimental setup for characterisation of thermometers at elevated temperatures and selectable vibration loads allows great insight into the interplay of vibrations and stability of thermometers which was not previously possible. Manufacturers of thermometers show great interest in this setup.

The lack of available data on spectral emissivity and lack of robust measurement equipment limits practical non-contact temperature measurement above 800 °C in an industrial setting. For this reason set-ups for the characterisation of Ni base alloys with respect to spectral emissivity have been developed and used to characterise Ni base alloys typically used in gas turbines. In order to test and improve the robustness of radiation thermometers dedicated high-temperature fixed points were developed for the calibration laboratory of a manufacturer of radiation thermometers.

Objective 2: Thermophysical properties

The second area of interest concerns research on thermophysical properties of high performance materials as they are used in turbines of gas power plants. The task was to develop and improve accurate reference facilities and methods for the measurement of thermal properties (thermal diffusivity, emissivity and specific heat) of homogeneous solid materials and Thermal Barrier Coatings (TBCs) at high temperature. The work undertaken by the project enables European NMIs to increase their capabilities in the measurement of high temperature thermophysical properties of refractory alloys and ceramic coatings. Before the project, it was not possible to ensure the traceability to the SI of these types of measurement above 800 °C. The facilities that were developed by the project are enabling these measurements to be performed up to 1500 °C.

The facilities were used for characterisation measurements on Ni-base alloys and TBCs (corresponding data were published). These metrological developments will therefore allow the better characterisation of the thermal properties of new high performance materials used in gas turbines, in order to increase efficiency of fossil fuel power plants.

Objective 3: Flow measurements

The main issue of research concerning flow measurements in power plants was to build up extrapolation models for different commonly used flow sensors in order to account for the fact that no facilities exist to calibrate the flow sensors at the high temperatures, flow rates and pressures that occur in power plants. The developed extrapolation models were experimentally proven to be metrologically valid and allow for a reduction of the uncertainty of flow rate measurements from approximately 3 % to 0.5 %. In particular the separation of effects due to temperature and flow profiles will result in improved parameter sets for flow meters and will lead to smaller measurement uncertainties. This is key to optimising the process control of power plants leading to increased energy efficiency.

Objective 4: Electricity measurements

In the field of on-site electricity measurements the project realised a complete system to perform fast and reliable electrical output measurements of a power plant with low uncertainty (better than 0.1% under laboratory conditions and 0.15 % on-site). The systemhas unprecedented capabilities in measuring the power output of power plants. Power plant operators showed interest in this setup especially for acceptance tests of power plants. Validation of a new power plant with better accuracy and will allow for increased confidence that a plant meets its specifications.

Impact

The project is directly related to the important European political issues concerning the enhancement of energy efficiency in order to save natural resources, promote the protection of environment and lower the emission of greenhouse gases.

The results of the project are relevant to a wide community of different and competitive companies responsible for construction, instrumentation and operation of power plants. In order to disseminate the findings of the project as fast as possible, high level representatives of these stakeholders formed an Advisory Committee.

Among this group of stakeholders the project is already creating impact:

- Manufacturers of thermometers used in power plants are now able to develop thermometers with low uncertainties of 3 K instead of 8 K. One of the manufacturers already offers commercially thermometers with these specifications.
- Manufacturers of flow sensors are now able to offer flow sensors with an uncertainty of 0.5 % instead of 3 %. Especially one manufacturer already sells an ultrasound based flow meter for the use in power plants with this specification.
- During the final stage of the project, some findings concerning temperature and flow rate measurements of this project were applied in the field. As performance tests in power plants are subject to strict confidentiality, it can only be stated, that after applying the findings of the project, two operators of power plants assume that the energy efficiency of each power plant could be enhanced by 1,5 percentage points as now the energy production processes can be optimised based on the low uncertainty measurements of flow rate and temperature.

Further impact is expected via:

- Manufacturers of on-site electricity power meters are now able to offer commercially measurement equipment with uncertainties of < 0.1 % instead of 0.5 %.
- Manufacturers of sensors for temperature measurement of turbine blades now have access to metrological infrastructure for further developments of the technique.
- Operators of power plants are aware of the project's outputs and there are significant opportunities for impact as the results are adopted more widely.

As there exists a strong economic interest for enhancing the energy efficiency in power plants, and the results have already been shared with the stakeholders during the lifetime of the project, it can be expected, that the aim of the project, enhancing the energy efficiency of power plants by 2-3 percentage points, will become reality within the next couple of years.

As stated above, the project was related directly to European energy policy. On a long term, after a representative number of power plants were operated at higher energy efficiency using the finding of this project, it might be possible that the use of better measurement techniques might be subject of European Legislation.

The environmental impact of energy efficiency gains is enormous, as it results directly in a lowering CO_2 emission and other greenhouse gasses. Currently, power plants, driven by fossil fuels, contribute to approximately 34 % of the CO_2 emissions and 40 % of the electricity worldwide. Improving the efficiency by 2 % will reduce at least 2 % of the CO_2 emissions worldwide. In addition, efficiency gains will preserve natural resources (gas, coal, nuclear fuel).

Publications:

No	Authors	Title	Journal	Details
1	B. Hay, J. Hameury, N. Fleurence, P. Lacipiere, M. Grelard, V. Scoarnec and G. Davée	New facilities for the measurements of high temperature thermophysical properties at LNE	International journal of thermophysics	DOI 10.1007/s10765-013-1400-8 (2013)
2	O. Büker, P. Lau and K. Tawackolian	Reynolds number dependence of an orifice plate	Flow measurement and instrumentation	30, 123-132, 2013
3	P. Klason, A. Andersson, M. Holmsten, P. Lau, G. Kok	A Speed Of Sound Based Feed Water Temperature Sensor	American Institute of Physics Volume 8 of Temperature: Its Measurement and Control in Science and Industry	AIP Conf. Proc. 1552, 925 (2013)
4	P. Klason, A. Andersson, M. Holmsten, P. Lau, G. Kok	Temperature Measurement In Flow Pipes – Comparison With Single Pt-100 And Multi Sensors	American Institute of Physics Volume 8 of Temperature: Its Measurement and Control in Science and Industry	AIP Conf. Proc. 1552, 987 (2013)
5	P. Klason, A. Andersson, M. Holmsten, P. Lau, G. Kok	Measuring temperature distributions in pipe flows	Advanced Mathematical and Computational Tools in Metrology and Testing IX, Series on Advances in Mathematics for Applied Sciences	vol. 84, Singapore, 2012, 20120404
6	K. Tawackolian, O. Büker, J. Hogendoorn and T. Lederer	Investigation of a 10-path Ultrasonic Flow Meter for Accurate Feedwater Measurements	Measurement Science and Technology	Vol. 25, No. 7, 075304
7	P. Klason, G. Kok, N. Pelevic, M. Holmsten, S. Ljungblad, P. Lau	Measuring Temperature in Pipe Flow with Non-Homogeneous Temperature Distribution	International Journal of Thermophysics	Vol. 35, Issue 3-4, pp 712-724 2014
8	T. Lederer, P. Klason et al.	Metrology for improved power plant efficiency the power plant project	Procc. ISFFM	Online available on: www.isffm.org June 2012
9	G. Rietveld, F. Diouf, X. Guo, E. So	The Establishment of a Reference System at VSL for On-Site Calibration of HV Revenue Metering Systems	CPEM 2012 conference digest	July 2012, 130 – 131
10	Ivan Jursic and Steffen Rudtsch	Thermal Stability of b-PtO_2 Investigated by Simultaneous Thermal Analysis and Its Influence on Platinum Resistance Thermometry	International Journal of Thermophysics 35 (2014), 1055-1066	DOI 10.1007/s10765-014-1695-0 (2014)
11	G. Rietveld, M. Fransen, E. Houtzager, and E. So	Reference system for on-site verification of HV revenu metering systems	Proc. Conference on Precision Electromagnetic Measurements (CEPM)	DOI 10.1109/CEPM.2014.6898436
12	R. Strnad, S. Rudtsch, K. Riski, M. Šindelář, M. Jelínek	Vibration Behaviour of a Thin-film Sensors in Power Plants	submitted to International Journal of Thermophysics	in the review process

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JRP start date and duration:	from 01 September 2010, for 36 months
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The EMRP is jointly funded by the EMRP participating countries within EURAMET and the European Union