EMPIR Call 2019 – Energy, Environment, Normative and Research Potential

Selected Research Topic number: **SRT-g12**
Version: 1.0

Title: Enhancing efficiency of high-temperature concentrated solar plants

Abstract

Future increases in energy demand, and planned cuts to greenhouse gas emissions by 2050, will have serious implications for the energy system. Consequently, more energy will need to come from renewable sources such as high-temperature concentrated solar plants. However, these plants currently require an energy efficiency enhancement of >10 % in order to optimise their cost-benefit ratio. Therefore, metrological research is urgently needed to optimise process control (flow, temperature), the thermophysical properties of the thermal energy storage materials and the properties of the absorption coatings. Such advances will facilitate the uptake of this technology and this will improve European energy security.

Keywords

Energy efficiency, flow-rate measurement, high-temperature concentrated solar plants, molten salt, renewable and clean energy, solar absorptance, solar emissivity, solar thermal energy, temperature measurement, thermal energy storage, thermophysical properties

Background to the Metrological Challenges

A renewable technology that is in need of further investment is concentrated solar power, which uses mirrors or lenses to concentrate sunlight onto a small surface area in order to generate the heat needed to drive a heat engine and an electricity generator. Process control is based on the measurement of the flow rate and temperature of the heat transfer fluid, e.g. molten salt, which is used to transport energy from the solar absorber to the heat exchanger and the heat storage facility (to bridge periods without sunshine). The mass flow is governed by the density and viscosity of the heat transfer fluid and the energy flow is governed by mass flow, specific heat and thermal conductivity. Accurate knowledge of these parameters is therefore mandatory for quantifying thermal power and for optimising the heat transfer circuit. High measurement uncertainties and low stability/durability of the flow and temperature measuring instruments enforce large safety margins in the operation of the molten salt in these plants. These sub-optimal operating regimes directly result in large efficiency losses (>10 %).

The flow rate of the heat transfer fluid needs to be measured at flow rates up to 1000 m³/h. However, the ultrasound flow rate sensors that are currently used often have to be replaced after two years as they are affected by corrosion. In addition, the flow rate sensors are currently calibrated using different fluids under laboratory conditions as there is no suitable primary flow standard available for use under real working conditions. Consequently, flow rate measurements lack full traceability and usually have large uncertainties of up to 12 % - 15 %. Therefore, alternative flow rate sensors, e.g. optical sensors, need to be investigated and an optimised traceability chain needs to be established with a full uncertainty budget.

The temperature of the heat transfer fluid needs to be measured at temperatures up to 600 °C. However, radiation-based temperature measurements usually have large uncertainties of 5 °C – 8 °C and resistive thermometers suffer from high drift due to their direct contact with the harsh environment. Therefore, traceable methods for performing non-, or minimally, intrusive multi-point temperature measurements need to be established. These might include methods based on the temperature dependence of the speed of sound (ultrasound based), optical (fibre optics, phosphor thermometry) and/or on other suitable methods in order to achieve a target uncertainty below 1 °C.

The thermophysical properties (specific heat, thermal conductivity) of thermal energy storage materials, such as molten salts, need to be more accurately and traceably determined across the range of planned operating temperatures. This data will be essential for the design of the absorber pipes and heat exchangers and to ensure the safe operation of the plants. At present, specific heat measurements, with an uncertainty of

< 2 %, are possible with specialist equipment, but this is only available in ~2 locations in the EU. In addition, the differential scanning calorimeters that are used to measure the specific heat of liquids cannot currently be calibrated as there are no liquid reference materials for calibrating these instruments. Consequently, the uncertainty of the specific heat values ascribed to molten salts can only be roughly estimated (~5 %). Therefore, accurate and traceable approaches need to be designed and developed for determining the thermophysical properties of the thermal energy storage materials.

The efficiency of concentrated solar plants is strongly based on the sophisticated solar absorption-coatings of the absorber pipes that heat the heat transfer fluid. The absorption-coatings need to be stable for > 15 years, strongly absorbing in the visible and near infrared (NIR) and low emitting in the mid infrared (MIR) and far infrared (FIR). However, only ~1 laboratory in the world is able to perform angular and spectrally resolved emissivity measurements up to 600 °C under vacuum conditions with uncertainties below 1 %, and only 1 European NMI can perform quasi-normal spectral absorptance measurements up to 600 °C with an uncertainty of ~2 %. In addition, these measurements cannot yet be performed on curved surfaces and suitable reference samples are not available with the required uncertainties. Measurements also need to be undertaken at working temperature rather than being extrapolated from measurements made at room temperature. Therefore, accurate and traceable methods need to be devised for determining the absorptance and emissivity, and information on the metrological requirements of the manufacturers of concentrated solar plants, is a requirement for any further development and optimisation of the absorption-coatings. Knowledge of the uncertainty on the ratio "solar absorptance/total hemispherical emissivity" is crucial for the calculation of the economic profitability of these plants.

Objectives

Proposers should address the objectives stated below, which are based on the PRT submissions. Proposers may identify amendments to the objectives or choose to address a subset of them in order to maximise the overall impact, or address budgetary or scientific / technical constraints, but the reasons for this should be clearly stated in the protocol.

The JRP shall focus on the traceable measurement and characterisation of concentrated solar plants.

The specific objectives are

1. To establish a traceability chain for ultrasound (non-intrusive clamp-on systems and intrusive multi-path systems) and/or optical flow velocity sensors for application in molten salt, which is used as heat transfer fluid, under working conditions with temperatures up to a minimum of 600 °C and flow rates up to 1000 m^3/h.
2. To develop traceable methods for non- or minimally intrusive multi-point temperature measurements in molten salt based on the temperature dependence of the speed of sound, optical and/or on other suitable methods with a target uncertainty below 1 °C.
3. To design and develop accurate and traceable approaches for determining the thermophysical properties (e.g. specific heat, thermal conductivity) of thermal energy storage materials, such as molten salts, with uncertainties small enough to enable the safe operation of concentrated solar plants at temperatures of more than 600 °C.
4. To devise accurate and traceable methods for determining the absorptance and emissivity of the solar absorption-coatings, which are used in concentrated solar plants, at up to 1000 °C with a target uncertainty below 3 %. These laboratory methods should enable the systematic improvement of the solar absorption-coatings as well as the quality control of the absorber tubes during production and installation in the field.
5. To facilitate the take up of the technology and measurement infrastructure developed in the project by the measurement supply chain (accredited laboratories, instrumentation manufacturers), standards developing organisations (CEN, ISO) and end users (e.g. concentrated solar plant operators).

These objectives will require large-scale approaches that are beyond the capabilities of single National Metrology Institutes and Designated Institutes. To enhance the impact of the research, the involvement of the appropriate user community such as industry, standardisation and regulatory bodies is strongly recommended, both prior to and during methodology development.

Proposers should establish the current state of the art, and explain how their proposed project goes beyond this.

EURAMET expects the average EU Contribution for the selected JRPs in this TP to be 2.0 M€, and has defined an upper limit of 2.3 M€ for this project.

EURAMET also expects the EU Contribution to the external funded partners to not exceed 35 % of the total EU Contribution across all selected projects in this TP.

Potential Impact

Proposals must demonstrate adequate and appropriate participation/links to the “end user” community, describing how the project partners will engage with relevant communities during the project to facilitate knowledge transfer and accelerate the uptake of project outputs. Evidence of support from the “end user” community (e.g. letters of support) is also encouraged.

You should detail how your JRP results are going to:

- Address the SRT objectives and deliver solutions to the documented needs,
- Feed into the development of urgent documentary standards through appropriate standards bodies,
- Transfer knowledge to the renewable and clean energy sector.

You should detail other impacts of your proposed JRP as specified in the document “Guide 4: Writing Joint Research Projects (JRPs)”

You should also detail how your approach to realising the objectives will further the aim of EMPIR to develop a coherent approach at the European level in the field of metrology and include the best available contributions from across the metrology community. Specifically, the opportunities for:

- improvement of the efficiency of use of available resources to better meet metrological needs and to assure the traceability of national standards
- the metrology capacity of EURAMET Member States whose metrology programmes are at an early stage of development to be increased
- organisations other than NMIs and DIs to be involved in the work.

Time-scale

The project should be of up to 3 years duration.