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Next Generation of Concentrated Solar Power Technologies †

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Abstract: This paper presents the results from the workshop organized by the NEXTOWER project aimed at creating a cluster and exchange forum for projects and research activities in the area of Concentrated Solar Power. Synergies and experiences were shared, common difficulties, specially when dealing with innovative materials were found and discussed and new collaboration opportunities where presented.

Keywords: concentrated solar power; innovative materials; thermal energy storage

1. Introduction

Next generation of Concentrated Solar power technologies was a workshop at the Conference Sustainable Places 2019 with the objective of providing a clustering framework of EU funded projects dealing with the next generation of concentrated solar power technologies. This workshop deals with two main issues around CSP technology: the need to develop, test and upscale new materials with higher performances and the need to reduce costs and open new markets for CSP projects via innovative and modular approaches and improved operations.

2. Presentations

2.1. NEXTOWER: "Innovative Solutions for Concentrated Solar Plant Towers"

NEXTOWER [1] is an ongoing effort to transfer (materials) technology across industrial sectors. Starting initially from nuclear materials, it creates a direct synergy with the Concentrated Solar Power Sector by delivering advanced materials for very high Temperature (e.g., >900 °C) and extreme (e.g., corrosive) applications environments.

In the scope of NEXTOWER the materials developed include new SiC ceramic receivers for high thermal gradient continued operations and innovative steels with improved resistance to corrosion by liquid lead contact.

In NEXTOWER liquid-lead is proposed as the material for energy storage (heat) integrated in the SOLEAD concept which is based on the experiences from the CIRCE cooling pool from ENEA.

From NEXTOWER developments it has resulted that liquid-lead corrosion at 800 °C is no-longer an issue for steels thanks to the innovative FeCrAl alloy. Tests are continuing on these materials, especially for the welded surfaces to ensure minimum corrosion attack.

Finally, on the ceramic materials, NEXTOWER has developed innovative high-temperature open volumetric receivers based on all-SiC honeycomb design for increased durability sand oxidation. Joined receivers have also been developed based on Si-SiC lattices optimised for higher toughness and thermal conductivity and using pressure-less techniques for the joining of the SiC pieces.

2.2. InPower: "Development and Integration of Innovative Material Solutions for CSP Technology"

The benefits of high efficiency concentrated solar power (CSP) and photovoltaic (PV) are well known: environmental protection, economic growth, job creation, energy security. Those technologies can only be applied properly in regions with annual mean radiation values higher than 1750 kWh/m^2 per year. CSP has advantages in front of PV: possible 24 h continuous electricity production, electricity and heat generation, heat for distributed in cogeneration plants. Within CSP, four technologies have been currently developed: parabolic trough collector (PTC), tower solar power, Stirling/dish collector and linear Fresnel collector with its advance type named compact linear Fresnel collector. In 2015, there is global 4GWe production (96% PTC), almost 3GWe are under construction. However, for huge deployment, a reduction of Levelized Cost of Electricity (LCOE) is imperative for industry consolidation, when nowadays is around 0.16–0.22 €/KWh depending on the size plant, Direct Normal Irradiance and the legal framework of site installation. CSP main components: solar field for solar to thermal conversion, power block for thermal to electrical conversion, and thermal storage system are the key to reduce LCOE. IN-POWER [2] project will develop High efficiency solar harvesting CSP architectures based on holistic materials and innovative manufacturing process to allow an Innovation effort mainly focus in advanced materials such as High Reflectance Tailored Shape light Free glass mirror, High working temperature absorber in Vacuum Free receiver, optimized Reduced Mass support structure allow upgrading current solar field. IN-POWER reduce environmental impact also by reducing three times standard thermal storage systems by novel thermal storage materials; and an amazing reduction four times the required land extension in comparison of current mature PTC power generation with the same thermal power output. IN-POWER solution will bring LCOE below 0.10 €/KWh beyond 2020.

2.3. RESLAG: "Turning Waste from the Steel Industry into Valuable Low Cost Heat Storage Material for CSP Applications: The REslag Project"

The European steel industry generates more than 20 million tons of slags per year from steel making. About 24% of this amount is not being reused, representing a severe environmental problem in Europe, but also a huge source of material for potential recycling.

The RESLAG [3] project aims at addressing this environmental problem by providing 4 eco-innovative industrial alternative applications to valorize the steel slag: extraction of nonferrous high added-value metals, thermal energy storage (TES) for high-temperature heat recovery applications, thermal energy storage in concentrating solar power (CSP) plants and production of innovative refractory ceramic compounds.

Regarding the CSP application, the possibility to use slags as heat storage material in single-tank thermocline TES systems is investigated. To that end, two different pilot TES units were built within the project, covering the application to plants using air and molten salts as heat transfer fluid, respectively. This presentation is focused on the latter pilot unit, which was recently commissioned at the ENEA Casaccia Research Center in Rome, Italy. Such TES system consists of a single vessel containing a packed-bed (3 m height, 1 m diameter) of solid pebbles produced by processing and sintering raw slags with a procedure set up within the project. In the different operating phases, molten salts are fed to the TES unit either from the top (thermal charging) or bottom (thermal discharging) and flown through the packed bed. The plant is completed by a secondary tank, which is used to pump the molten salts in the circuit and collect them when the plant is drained, an electrical heater and an air cooler, which allow to control the temperature of the molten salt stream fed to the TES unit, in order to simulate the different operating phases. The facility operates in the temperature range 290–550 °C, with molten salt mass flux in the range 0.45–1.5 kg s^{-1} m^{-2} and the TES unit has a nominal capacity of about 480 kWh (thermal). The first experimental campaign on the pilot unit will be completed within July 2019.

2.4. CySTEM: "Contribution of the CySTEM ERA Chair H202O Project to Enhance the Research Capabilities of the Cyprus Institute in Concentrating Solar Thermal Technologies"

The H2020 project, European Research Area (ERA) Chair in Solar Thermal Energy for the Eastern Mediterranean (CySTEM) [4], aims at consolidating and upgrading the already substantial activity at the Cyprus Institute (CyI) in Solar Energy and related technologies. To achieve this, the ERA Chair is working in close coordination with the CyI top management to:

- Attract outstanding researchers that will reinforce the existing CyI's Solar Energy and Desalination (SED) Group.
- Pursue a Scientific Work Programme of excellence in Cyprus with local and regional focus in the region of Eastern Mediterranean and Middle East (EMME).
- Maximally utilise the existing solar research facilities, upgrade and operate them at the appropriate level to support the Scientific Work Programme effectively.
- Continuously improve the professional skills (both technical and managerial) of the members of the SED Group, their productivity, and engagement so that the group will be always aiming for excellence in everything it does.

The principal focus of the Scientific Work Programme is on Concentrated Solar Thermal (CST) technologies for electricity production, desalination, air conditioning and heating, used either in isolation or in multi-generation mode. Within this field, the ERA Chair and his team are working on:

- The development of an open source ecosystem for automatizing the design of high concentration optics.
- The incorporation of Artificial Intelligence techniques to assist in the optimization of difference components and subsystems of CST systems.
- The development of open source Modelica components tailored to simulate and optimize CST systems at high-level.
- The development of overall Energy System modelling tools to explore and forecast the future energy mix at a national or regional level, and to assess the impact on the overall energy system of deploying specific CST systems.
- The enhancement of the testing capabilities of the SED Group, by installing a BSRN solar radiation and meteorological station; building a test bed for flux measurement system; and developing technologies for enhancing the geometric characterization of CYI's heliostat field.
- The experimental validation of the computer tools being developed.

2.5. Polyphem: "Small-Scale Solar Thermal Combined Cycle: The Project POLYPHEM"

POLYPHEM [5] is a Research and Innovation Action granted by EU H2020 program. The project is carried out by 4 research centers and 5 private companies. The main objective of POLYPHEM is to improve the flexibility and the performance of small-scale Concentrated Solar Power plants featuring a solar thermal combined cycle coupled to a thermocline thermal storage system.

The technology consists of a solar-driven micro gas-turbine as top cycle and an Organic Rankine Cycle as bottom cycle. A thermal energy storage using thermocline technology is integrated between both cycles. The resulting power block is a solar power generation system able to meet the requirements of a local variable demand of energy with a high average conversion efficiency and a low environmental profile.

The project will build a 60 kW prototype plant with a 2 MWh thermal storage unit. It will validate this innovative power cycle in the relevant environment of the Themis solar tower experimental platform in France (see Figure 1). The technical, economic and environmental performances will be assessed and the guidelines for its commercial deployment will be established at the end of the project.

The project started in April 2018. The main results achieved to date are:

- The Ni-based alloy 230™ (Ni-Cr-W-Mo) has been selected for the construction of the solar receiver.
- The initial design of the solar receiver is completed. This key component is made of absorber modules arranged in a surface receiver. The air flows into the modules through manifolds placed on each side of the absorber plane.
- The engineering for the solarization of the gas turbine is done. Air ducts connect the engine to the solar receiver.
- The concrete grades used for the construction of the thermocline tank wall and for the storage filler are identified. These materials have been characterized and the compatibility with the thermal oil has been proven.
- The initial design of the storage tank is completed.
- The overall plant layout is established.
- The system modelling is started.

2.6. MOSAIC: "CSP Plant Concept for the Highest Concentration Ratios at the Lowest Cost"

The MOSAIC [6] project aims to develop a commercial CSP plant concept over 1GW nominal capacity. High nominal capacity is reached in a modular way, where each MOSAIC module delivers thermal energy to connected thermal energy storage systems that supply their energy to a high capacity power block (>1 GW). This modular configuration significantly reduces the specific cost of the power block (€/MW installed). Each MOSAIC module consists of an innovative fixed spherical mirror concentrator arranged in the form of a semi-Fresnel and a moving receiver driven by a low-cost cable tracking system. This configuration reduces the amount of moving parts of the entire system, lowering the cost of the solar field and keeping high concentration ratios. This will ensure high working temperatures and therefore high cycle efficiencies and cost-effective use of thermal storage systems. Energy from the sun is collected, concentrated and transferred to the heat transfer fluid at module level, where, due to the modular concept, the distances from the solar concentrator to the receiver are much shorter than in typical solar tower technologies. As a result, energy collection efficiency is maximized, atmospheric attenuation is minimized, and precision requirements can be lowered. All these technical benefits can contribute to a lower capital cost of the whole system, while ensuring efficiency and reliability. This therefore has a strong impact on the final cost of electricity production.

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