Coatings for Use at High Temperatures
Room Royal Palm 1-3 - Session A3

Materials and Coatings for Solar Power Concentration Plants

Moderators: Vladislav Kolarik, Fraunhofer Institute for Chemical Technology ICT, Gustavo García-Martín, REP-Energy Solutions

2:30pm **A3-4 Corrosion Impact Of Alkali Carbonate At 750°C On Nickel Base, Stainless Steel And Alumina Forming Ferritic Steels*, Christine Geers,*** Chalmers University of Technology, Sweden

A carbonate mixture containing equal amounts of lithium, sodium and potassium was investigated in respect to its corrosive impact on metallic materials at 750°C to meet the demand of increased operation temperatures in concentrated solar power plants. A constant carbon dioxide feed was applied to suppress salt decomposition during exposure. Rapid oxidation and internal corrosion by carburization are characteristic consequences of carbonates in contact with steel at high temperatures. Significant differences in oxide scale stability and carbon ingress have been found for the three alloy classes after a maximum exposure time of 740 h. Depending on which oxide scale is formed, chromia or alumina, the corrosion features change from general to local occurrences pointing towards a high permeability of the oxide scale in the case of chromia formers compared to alumina formers where only locally non-protective behavior was observed. These observations are in agreement with findings from experiments in “solar salt” where major differences between alloys was also coupled to different oxide species and characteristics formed at the surface, independent of the permeating species which was nitrogen in that case.

2:50pm **A3-5 Challenges of New Materials and Coatings for Solar Receivers and Reflectors in Concentrated Solar Power Plants*, Florian Sutter,*** German Aerospace Center (DLR), Spain*; Y Binyamin,* Brightsource Industries, Israel*; A Agüero Bruna,* Instituto Nacional de Tecnica Aeroespacial (INTA), Spain*; C Hildebrandt,* Fraunhofer ISE, Germany*; D Fähsing,* DECHEMA Forschungsinstitut, Germany*; A Morales, A Fernandez-Garcia,* CIEMAT, Spain*; F Pérez-Trujillo,* Universidad Complutense de Madrid, Spain **INVITED**

With increasing share of fluctuating wind and photovoltaic power generation, Concentrating Solar Power (CSP) technologies with thermal storage become more important due to their flexibility in dispatching power to the grid. The International Energy Agency envisions that the global electricity share of CSP systems will reach 11% by 2050, provided that the CSP technology achieves significant cost reductions. One approach to meet this goal is the use of novel materials and coatings to increase the plant efficiency and to enhance lifetime.

This work reviews several new materials with potential to be applied in future CSP plants. In the low temperature range, protective coatings to prevent silver corrosion of glass mirrors will be discussed. In addition, experimental results of anti-soiling coatings to reduce the soiling rates on the mirror surface will be presented. In the medium temperature range (up to 400°C), novel selective absorber coatings operating in air or vacuum are described, as well as anti-reflective coatings with increased abrasion resistance. In the high temperature range (up to 750°C) a set of new high solar absorptance coatings for solar towers will be presented, as well as protective coatings for stainless steels to prevent corrosive attack from molten nitrate salts used as heat transfer and storage medium.

The above described materials are undergoing severe accelerated lifetime tests to ensure that they meet the challenging and harsh operating conditions, which materials need to face in CSP plants. The performance and expected lifetime of the prototype materials is compared to the state of the art.

3:30pm **A3-7 Corrosion Testing of Diffusion-coated Steel in Molten Salt for Concentrated Solar Power Plants*, Diana Fähsing,*** *T Meissner, M Galetz,* DECHEMA-Forschungsinstitut, Germany

In the course of energy transition the development of sustainable technologies for power generation providing base load supply is of particular importance. In comparison to photovoltaics Concentrated Solar Power (CSP) Systems have great potential to fulfil this requirement by the use of thermal storage systems employing molten salt mixtures as heat transfer fluids. For this purpose, molten nitrates are frequently discussed due to their beneficial thermal and physical properties as well as high working temperatures. These fluids are circulated through the superheaters of the CSP receiver for heat absorption, which is subsequently transferred to a steam generator for power generation.

While the receiver tubing's external surfaces are exposed to dust erosion as well as to fluctuating high temperature profiles, its insides are attacked by mechanisms from molten salt corrosion. In order to protect the piping system from degradation coatings can be applied to the materials in use which are commonly steels or Ni-based alloys. The goal is to achieve cost reduction to ensure an even more competitive position of the CSP technology with respect to other renewable sources on the market.

In this study, the behaviour of coated and uncoated ferritic-martensitic steels of type T91 and VM12 in molten salt (mixture of $NaNO_3$ and KNO_3) has been investigated under isothermal conditions. The diffusion coatings are based on potentially protective elements such as Al, Si or Cr and were applied to the steels either by pack cementation or slurry aluminization. Characterization of the samples was conducted by means of optical microscope, EPMA and XRD analysis in order to gain deeper understanding of the occurring corrosion mechanisms and for the purpose of life expectancy analysis.

3:50pm **A3-8 High Temperature Molten Salt Corrosion Behavior of Aluminide and Nickel-aluminide Coatings for Heat Storage in Concentrated Solar Power Plants*, Pauline Audigié,*** *S Rodríguez, M Gutiérrez,* Instituto Nacional de Técnica Aeroespacial (INTA), Spain*; V Encinas-Sánchez, F Pérez-Trujillo,* Complutense University of Madrid, Spain*; A Agüero Bruna,* Instituto Nacional de Técnica Aeroespacial (INTA), Spain

Thermal energy storage (TES) in concentrated solar power (CSP) plants is still a key issue as CSP plants are subjected to intermittency of the Sun. Using suitable TES systems is so of great interest. Currently, CSP plants use the so-called Solar Salt (60% $NaNO_3$ - 40% of KNO_3) as heat storage system which is considered to be stable, and has adequate heat storage and transfer capability. However, the maximum storage temperature is limited to 580ºC. New molten salt mixtures with higher temperature stability point are therefore required to increase the plants efficiency, all of this without increasing cost. In general, molten salts can be very corrosive to metallic components in direct contact with them and the corrosion resistance of the materials used for tanks or tubes depends on the formation of a protective oxide scale, which is similar to the protection mechanism occurring during oxidation in high temperature gaseous atmospheres. However, an important difference when using molten salts is that Cr, a protective oxide former, can be soluble in some salts mixtures preventing the formation of the oxide. This results in non-protective and/or fast-growing oxide formation and in the increment of material degradation due to higher corrosion rates. The use of coatings to prevent molten salt corrosion can be a solution. Slurry aluminide coatings are a low cost alternative that allows uniform coating of internal surfaces. Recent studies *[Dorched et al. 2016, Audigié et al. 2017]* have demonstrated the good behavior of these coatings but the protection mechanism is still not well identified. Moreover, since increasing nickel content in Ni-base alloys improved alloy corrosion resistance to molten nitrate-nitrite salt, newly developed nickel-aluminide coatings deposited on 9 wt.% Cr P91 were also tested in contact with molten salts. In this work, sprayed slurry aluminide and nickel-aluminide coatings deposited by means of electrodeposition and slurry application to 9 wt.% Cr P91 alloy have been characterized and both systems have been tested isothermally at 580ºC in contact with the Solar Salt and at 650ºC with a ternary molten salts mixture based on Na, K and Li carbonates. Both tests have been carried out under static and dynamic conditions. All the coated systems in contact with both salts up to 1000h performed much better than the uncoated material as they exhibited very slight weight variations and formed very thin Na or Li aluminates. On the contrary, the uncoated P91 developed a complex, fast growing multilayered oxide scales experiencing significant metal loss which was calculated after removing the corrosion products by chemical etching.

4:10pm **A3-9 High-Temperature Coatings for Protection of Steels in Contact with a Novel Molten Salt under Static and Flow-Accelerated Conditions for CSP Technology*, V Encinas-Sánchez, M Lasanta, M de Miguel, G García-Martín, Francisco Javier Pérez-Trujillo,*** Complutense University of Madrid, Spain

The dramatic increase in demand for energy independence and inclination towards renewable energy as a sustainable and green energy source have led research groups all over the world to concentrate their investigation on solar power. As renewable energy penetration grows, the need for utility-scale renewable generation with storage technology is increasingly important to mitigate intermittency problems, deliver power to peak demand periods and support transmission system reliability. Hence,

concentrated solar power has gained momentum as an attractive technology. Molten nitrate salts are currently considered ideal candidates for heat transfer and storage applications because of their properties. However, this technology is still expensive compared to other renewable sources, which lead to propose solutions for reducing costs, such as development of new mixtures with greater work-temperature range. This increase in temperature limits would strongly require the use of alloys known for their high cost compared to other steels, such as ferritic-martensitic steels. According to this scenario, the use of high-temperature corrosion-resistant coatings would be a very suitable option, even more if they were deposited on ferritic-martensitic steels. This solution not only would help to overcome the corrosion problems of using ferritic-martensitic steels at higher temperatures, but also would allow the CSP industry to improve the Levelized Cost of Energy by reducing Operating & Maintenance costs. In this respect, alumina-based and zirconia-based sol-gel coatings seems to be a great option, both from an operational and economical point of view.

In this work, sol-gel alumina-based and zirconia-based coatings deposited on P91 has been tested in contact with a proposed novel molten nitrate salts at 560°C, results being compared with the uncoated substrate. The study was developed up to 1000 h under static and flow-accelerated conditions, the latter being performed in a novel pilot plant facility, patented under the reference code WO2016102719. Samples were characterized via gravimetric, SEM-EDX, and XRD. Also corrosion was monitored by electrochemical sensors, patented under the reference code WO2017046427.

Results showed the good behavior of the coated substrates, with very little weight gain after 1000 h of test in comparison with the uncoated ones, which exhibited significant weight gain and spallation. The good behavior of the proposed coatings was also observed by SEM-EDX and XRD. Furthermore, corrosion monitoring system showed the protective behavior of the coatings, these being compared with the uncoated samples, where widespread corrosion was determined.

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