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Materials corrosion for thermal energy storage systems in concentrated solar power plants

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A B S T R A C T

The current commercial deployment of concentrating solar power (CSP) relies on a system of thermal energy storage (TES) for round the clock generation of electricity. The heat harvested by a system of collectors, either parabolic troughs or a heliostat field, is transferred by means of heat transfer fluid (HTF) to a storage tank, where it is kept until required for power generation. In the implemented systems, the storage of heat is accomplished by a mixture of salts characterized by an optimum set of properties required at the desired temperatures of operation. In liquid phase, the salt mixture represents an ionic conductor providing conditions for electrochemical degradation of materials when in direct contact. The risk of materials failure is further increased by thermal cycling and the possibility of mechanical stress. This paper describes the possible corrosion issues that might affect a TES system considering generalized and localized corrosion, as well as flow accelerated and mechanically assisted corrosion for the specific operation conditions of CSP plants. A comprehensive summary of uniform corrosion rates determined for common and less common alloys considered for application in TES is provided, along with discussion of the applicability for evaluation of possible corrosion damage in an actual CSP plant.

1. Introduction

The interest in alternative sources of energy has been motivated by increased demand for energy associated with growing world's population, industrialization and limitation of conventional energy sources, as well as the concern of potential impact of conventional fossil sources on the global climate. One of the promising alternatives is the use of solar energy, mainly motivated by the amount of energy reaching Earth from the Sun, matching in one hour the planet's annual consumption [1]. In this context, areas of high insolation identified by the high values of direct normal irradiance (DNI) shown in Fig. 1, are naturally privileged and the technology of producing solar-based electricity is already employed in places like Sahara (Africa), Arizona (USA), Victoria (Australia) and Atacama Desert (Chile) [1–3].

The two principal technologies used for transforming solar radiation into electricity are photovoltaics (PV) and concentrated solar power (CSP). Whereas in the first case, electricity is produced directly by a solar cell employing the photoelectric effect, the CSP technology involves storing thermal part of the solar energy which is further used for generating electricity in a power-producing heat process. The CSP approach has gained particular interest for large scale applications due to its potential efficiency and relatively low environmental impact, as well as the possibility of including energy storage systems [5]. In recent years the installed capacity of the CSP technology has increased to 4.8 GW (Fig. 2), with Spain and USA being the first adopters and the technology can be expected to keep developing in the future.

The operation of a CSP plant consists in concentrating the sunlight using mirrors onto a system containing heat transfer fluid (HTF), which is then conducted to a power-block for generation of electricity. Optionally, HTF can be transferred to an auxiliary storage system, often referred to as of thermal energy storage (TES), where it is withheld at elevated temperature until the requirement for electricity generation arises [5,7]. TES allows leveling the electric output from eliminating the short-term variations associated with natural sunlight up to translating the generation of electricity from the solar hours to the evening hours at which the demand is typically the highest. The roadmap for

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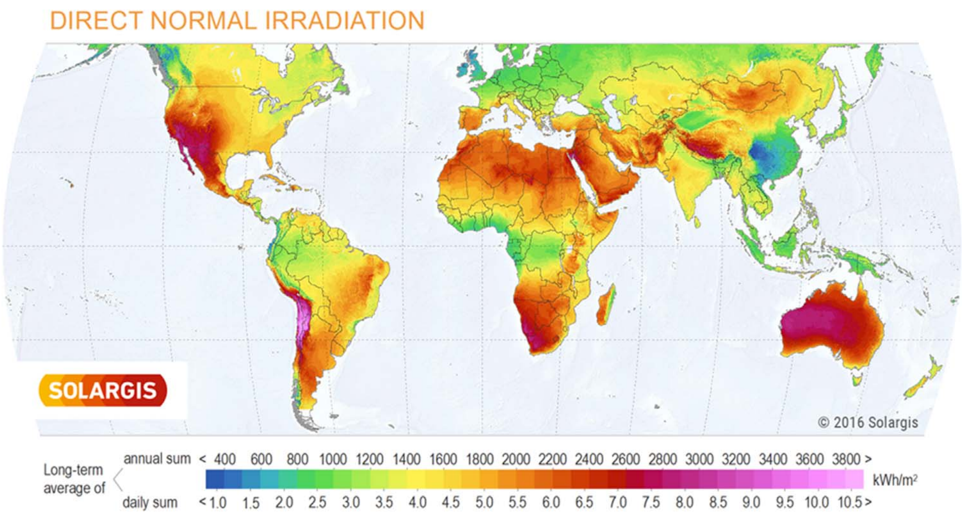

Fig. 1. Annual distribution of direct normal irradiation (DNI) in the world [4].

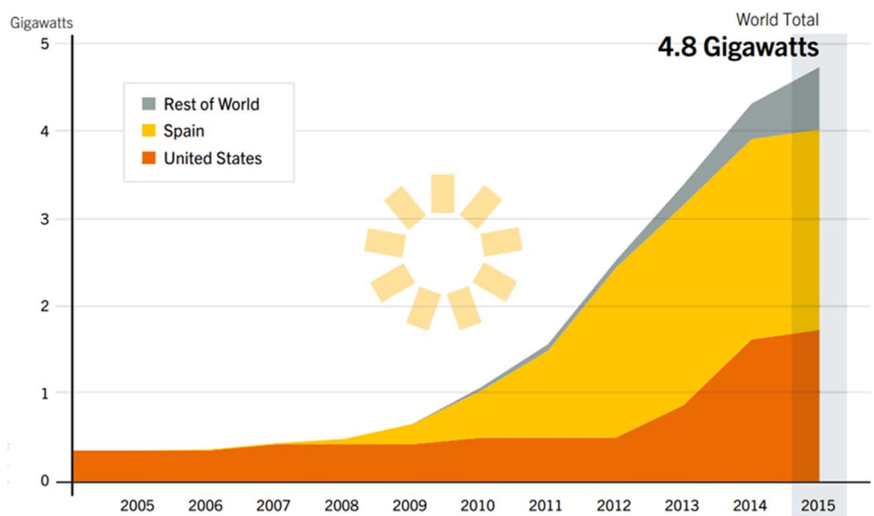

Fig. 2. Global cumulative capacity of CSP by country [6].

CSP technology envisions its use to provide 11% of total electricity generation by 2050 for a high-renewable scenario, or 6% for the 2 °C scenario (2DS), according to the "Energy Technology Perspectives" by the IEA [8]. However, for these growth scenarios to be the case and for the CPS-based solar energy generation to be efficient and safe, there are several issues that still require addressing. Lowering the costs of technology is one of the most pressing and it involves considering new materials, receiver concepts and configuration designs, both in terms of initial cost and the context of long term integrity of the entire system. The performance and stability of the materials exposed to cycles of high temperature, mechanical stress and possibly UV radiation associated with operation of a CSP plant are of particular importance. With this motivation aims at quantitative comparison of corrosion performance of common structural materials considered for the technology so far. In this context a summary of materials and components is presented, followed by description of the involved corrosion mechanisms and techniques of their study. Then literature data on corrosion rates is analyzed, and finally the possibilities of mitigation and the remaining challenges imposed by further development of the CSP technology are indicated.

2. Components and materials of concentrated solar power plants

A typical CSP plant consists of: i) mirrors to redirect DNI to an absorber ii) a system of heat transfer to convey the captured heat to a power cycle, iii) system of thermal energy storage to maintain the energy supply throughout a 24 h day, and optionally iv) back-up system to aid the control of electricity generation [1,7,9].

Customarily, three generations of CSP technology are distinguished: Gen1 and Gen2 differing in the type of collector and using the same type of salt for thermal storage (nitrate), and Gen3 employing a different salt for TES (carbonate) [10].

Collectors utilize optical elements to focus large amount of radiation onto a small receiving area and, at the same time, modify their geometric orientation to follow the apparent position of the sun throughout its daily path to maintain the maximum solar flux at the heat absorber. Heat collection can be achieved by any of the following designs: i) parabolic trough collector (PTC), referred to as Gen1 CSP, ii) solar tower (ST), referred to as Gen2 CSP, iii) linear Fresnel reflectors (LFR), or iv) parabolic dish collector (PDC). In this paper only the two first technologies are considered, as they exhibit a higher level of commercial maturity and concentrate the largest percentage of current installed capacity [5].

A PTC configuration, shown schematically in Fig. 3, is the most adopted CSP technology with several projects in operation (Table 1). The collecting elements consist of a parabolic-shaped mirrors focusing DNI to a receiver tube containing HTF. In order to maximize the energy production, the collectors are equipped with a tracking system to adjust