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Degradation of receiver tube optical performance after four years of operation

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ABSTRACT

The performance of parabolic trough receiver tubes has a direct impact on concentrated solar power plant production and thus must be maintained at as high a level as possible during the life cycle of the plant. In this paper, in-the-field degradation of commercial plant receiver transmittance and absorptance is studied after four years of operation. Since no records of similar measurements were available regarding the reception of the receivers, the results are compared with both the manufacturer's technical specifications and with the guaranteed values. For this purpose, the Mini Incus portable spectrophotometer developed by Abengoa is used to measure the optical properties of an 80-receiver sample. This sample is built up considering the two main factors most likely involved in transmittance and absorptance degradation: interactions with external agents and operating temperature. Therefore, receivers from different locations both in the field and within loops are chosen. A statistical study is performed on the data collected in order to obtain representative values for the whole population of evaluated receivers as well as for every group differentiated. The results reveal no significant degradation of the absorptance or transmittance of the receivers, with measured average transmittance and absorptance values of 96.6 ± 0.2% and 95.9 ± 0.2%, respectively, higher than the 96% and 95% indicated in the technical specification for new first generation receivers. Receiver location in the field and position within the loop does not influence optical property degradation, since the appreciated differences fall within the uncertainty of the measurement device. The obtained results are then compared with the technical specification values and with those guaranteed by the manufacturer after 4 years of operation, and the suitability of the guarantee in matching the reality experienced by the receivers in the field is discussed.

1. Introduction

Around 95% of the current CSP installed worldwide is derived from parabolic trough collector systems (CSP Today, 2014). In such systems, solar to thermal energy conversion depends on receiver tube performance and thus the latter represent one of the key components in this type of CSP plant (Forristal, 2003). As a consequence it is essential to monitor the real behaviour of receivers throughout their operating life, as well as the influence of external agents on their optical properties. However, to the authors' best knowledge, the literature makes no reference as to receiver optical property evolution long-term operation in the field.

Certain earlier studies (Kutscher and Netter, 2014; Pernpeintner et al., 2009) introduced indirect methods in order to evaluate the combined thermal and optical efficiency of a receiver. However, such methods require a complex setup and are associated with a high level of uncertainty due to the variety of factors involved in the indirect measurements. Moreover, they cannot be applied during the operation of receivers installed in the field but rather only to isolated receivers. Sanchez et al. (2010) claimed the existence of characterisation equipment able to make direct measurement of the optical and thermal performance of isolated receivers under laboratory conditions, but no results were shown. Pernpeintner

Abbreviations: CSP, concentrated solar power; AR, antireflective; SCA, solar collector assembly; ASTM, American Society for Testing Materials; HTF, heat transfer fluid.

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Nomenclature

α	absorber tube absorptance
τ	glass envelope transmittance
ε	absorber tube emittance
ρ	absorber tube reflectivity
w	receiver tube efficiency
μ_τ	average transmittance
σ_τ	standard deviation of transmittance
μ_α	average absorptance
σ_α	standard deviation of absorptance
μ_w	average receiver tube efficiency
σ_w	standard deviation receiver tube efficiency

et al. (2015) stated the importance of durability tests for parabolic trough receivers and evaluated the degradation of the glass cover AR coating by abrading small samples with a rubber tool. However, no relationship was established with which to define the equivalence of intensity between the tested abraders and the environmental factors affecting the receiver glass cover during its lifetime, such as dust, soiling, wind, etc. The latter study is thus not comparable with actual field conditions. Finally, Espinosa-Rueda et al. (2014) presented, for the first time, direct measurements of transmittance and absorptance of receivers installed in an operational commercial plant. In this case, the scope of the study centred on the soiling ratio and its evolution during a short period of 16 days, with no discussion made as to the degradation of receiver optical properties. Similar analyses, (Cohen et al., 1999; Fernández-García et al., 2014; Sarver et al., 2013) have been carried out on CSP reflectivity mirrors. In some of these studies (Fernández-García et al., 2010) the relevance of evaluating the receivers was openly recognised but discarded due to their inaccessibility.

Receiver tube performance depends on three parameters (Forristal, 2003; Price, 2003): the transmittance (τ) of the glass outer tube and the absorptance (α) and emittance (ε) of the inner tube. Here transmittance is defined as the proportion of solar energy transmitted through the glass tube with respect to the total solar energy incident on it. Although borosilicate glass offers a good compromise between high transmittance and mechanical resistance, this optical property is typically increased by applying an AR coating to both the inner and outer surfaces of the glass (Lari et al., 2015). Therefore, the conservation of both this layer and that of the glass itself by avoiding scratching etc., is essential in order to maintain the transmittance at its highest level. However, when a receiver is installed in the solar field and operated on a regular basis, multiple external agents such as soiling, dust, ambient dryness or humidity, rainfall, artificial cleaning and, of course, ageing, interact with its outer surface and possibly degrade its properties (Navarro and Martinez, 2015). Soiling can adhere to the receiver surface and rest on the AR coating (Espinosa-Rueda et al., 2014), with wind then blowing and dragging the particles along the surface. Washing trucks apply a specific cleaning method for receivers, while ageing may also have an effect on the optical layer. A combination of many factors may thus lead to a degradation of transmittance and therefore to a decrease in receiver efficiency. If external agents are taken to be the main source of such interactions, the location of a trough within the solar field must be considered when analysing receiver degradation.

In contrast, absorptance is defined as the proportion of solar energy collected by the inner tube with respect to the total solar energy incident on it. This property is defined by the absorber coating sputtered on the surface of the inner tube (Platzer and Hildebrandt, 2012) and thus this coating's correct conservation is essential in order to maintain the absorptance at its original level. For this purpose, as well as to avoid thermal losses, the receivers contain a vacuum chamber between both tubes, creating a protective atmosphere for the absorber coating (Liu et al., 2016). However, receivers installed in the solar field and operated on a regular basis are subjected to temperatures up to 400 °C, which may have an effect on the absorber coating in the long-term. As this particular operating temperature depends on receiver position within the loop, it seems logical to consider this variable in the analysis of absorption degradation.

The evolution of receiver optical properties is not trivial, since manufacturers guarantee their values for only a short and limited period of time. Analysis of the state of receivers after some years of operation is thus necessary to establish an accurate performance scenario of this important component. The present paper is the first to describes, at least to the best of this author's knowledge, the evaluation of both transmittance and absorptance in a sample of receivers from a real commercial parabolic trough plant after four years of operation.

2. Evaluation procedure and measurement device description

The power plant under study was a 50 MW CSP parabolic trough plant located in Seville (Spain), with a north–south orientation. After 4 years of continuous operation and having the necessary means, a receiver evaluation was carried out in order to obtain information as to the degradation or conservation of their optical properties over this considerable period of time. During this period, the guidelines recommended by the receiver manufacturer with which to conserve the glass tube AR coating, and therefore its transmittance, in a good state were followed. To this end, the receivers were cleaned using water sprayed at a pressure under 20 bars, with the distance between the nozzle and glass tube greater than 40 cm, the nozzle angle above 25° and using demineralised water with a quality under 1 μS/cm. The receivers were cleaned at a minimum frequency of once a week, a rate considered sufficient to avoid receiver oversoiling since the average soiling ratio of the plant is between 0.1 and 0.2%/day, as described by Espinosa-Rueda et al. (2014).

Since the AR coating of the glass tube can be affected by external agents, its exposure to the open field and subsequently also the position of the troughs within the solar field (perimeter, interior, etc.) must be considered when analysing any possible degradation experienced by the receivers over time. Therefore, four types of trough were defined according to the four different positions of troughs in the solar field as described by Espinosa-Rueda et al. (2014): east and west, north and south, inner and around the cooling tower troughs (Fig. 1).

In this case the east and west troughs are the most exposed to the open field, followed by the north and south troughs. These troughs are thus most affected by vehicles driven along the perimeter sand roads, dusty winds, or any other similar factor. For troughs positioned around the cooling tower, their location is such that relative humidity is higher than in the rest of the plant, making air-borne pollutants such as dust stick harder to the receiver glass surface. Finally, inner troughs are effectively shielded by the rest of the troughs, protecting them from the described external agents.