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Vacuum evaluation of parabolic trough receiver tubes in a 50 MW concentrated solar power plant

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ABSTRACT

The solar receiver tube is a key component in the parabolic trough solar thermal power system. The loss of vacuum or degradation of the receiver has a significant impact on the receiver's thermal performance and is the single largest cost factor in parabolic trough solar power plants. This paper presents a procedure to evaluate the annulus gas and thermal performance of receivers in the solar field. It is based on the glass and absorber temperatures of receivers as well as on plasma generation in the annulus space. The procedure has been executed in a 50 MW commercial plant after five years of operation. 9% of receivers operating in the solar field showed vacuum loss to some degree. A sample of 70 receivers showing degradation were individually evaluated, of which: 34% of receivers showed progressive oxidation of the absorber coating, one receiver was measured to have argon in the annulus space at 10^{-2} mbar pressure, and the remainder showed glass temperatures corresponding to those with air being the gas in the annulus. Temperatures measured in the receivers' glass envelope did not match those with hydrogen being the gas in the annulus. Hydrogen was not found either by plasma generation. Heat losses under operating conditions added up by the found vacuum losses have been estimated over the reference performance of a solar field keeping its initial vacuum. The full procedure, measurements, results and discussion are described in this paper, aiming to understand as fully as possible the cause of the loss of vacuum experienced by the receivers.

1. Introduction

Most of the CSP power plants currently installed worldwide correspond to parabolic trough technology, which bases the conversion from solar to thermal energy on the receiver tubes. Receivers play an important role in the solar field efficiency of CSP plants, and knowledge of their performance is a relevant issue in this technology (see Fig. 1).

The performance of receivers is defined by their optical and thermal efficiency (Pernpeintner et al., 2009). Some references can be found in the literature describing their optical features. Kutscher and Netter (2014) proposed a method for measuring the optical efficiency of evacuated receivers. Espinosa-Rueda et al. (2014) presented the first in-the-field measurements of receivers' transmittance and absorptance during a period of real operation. Navarro and Martinez (2015) carried out a study on different cleaning methods for receivers, aiming to optimize their glass transmittance.

Thermal performance has been described by thermodynamics models (Forristal, 2003), characterized in the laboratory (Burkholder and Kutscher, 2009; Lei et al., 2013) and evaluated through tests in the field (Lüpfert et al., 2008). It is determined by the pressure in the annulus space, as well as by the emittance of the solar-selective coating, for given boundary conditions and operating temperatures. Receivers present a vacuum annulus between the absorber inner tube and the glass outer cover in order to reduce inner convection losses and to preserve the absorber coating from oxidation (Li et al., 2012a). For this purpose, they are manufactured with an annulus pressure below 10^{-3} mbar,

Abbreviations: CSP, concentrated solar power; SEGS, solar energy generating systems; AGA, annulus gas analyzer; HTF, heat transfer fluid; EES, engineering equation solver; IFOV, instantaneous field of view.

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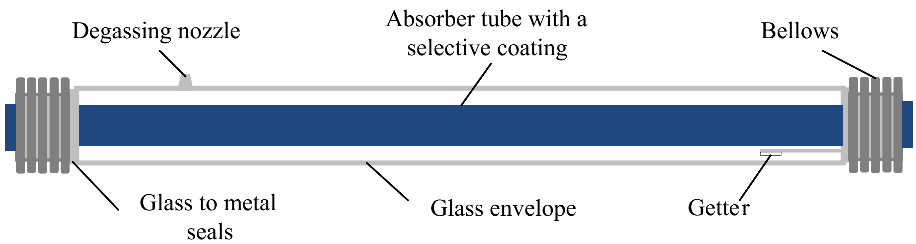

Fig. 1. Schematic of a typical parabolic trough receiver.

lower than the Knudsen gas conduction range, to guarantee the good performance of the tubes during their 25-year lifetime. However, it has been reported (Price et al., 2006) how some receivers lose their vacuum due to incoming gas, significantly increasing their heat losses and showing the so-called "hot tube phenomena". References in literature (Wang et al., 2011) claim the vacuum to be mostly degraded by hydrogen, which is generated by exposing the HTF at high temperatures above 400 °C (Moens and Blake, 2008). This hydrogen is said to diffuse through the absorber tube walls, coming into the annulus space (Li et al., 2012a,b). Receiver manufacturers base their design on this assumption, placing getters (Liu et al., 2016), metallic compounds designed to absorb gas molecules, inside the receiver. In this paper, the vacuum loss phenomenon has been studied on real receivers under operation: an experimental analysis of the gas composition in the annulus space is performed on receivers under operation in a 50 MW commercial plant. In order to do so, a novel device is used: the AGA, able to identify the gas composition and pressure through a non-destructive test.

2. Measurement and evaluation methods

2.1. Instruments

Three devices have been used to carry out the evaluation of the receivers in the field: the AGA, the Thermohook and an Infrared Thermocamera. These pieces of equipment are described in the following paragraphs.

The first instrument is the AGA, a portable device developed by Abengoa in collaboration with Instituto de Ciencia de Materiales de Sevilla, which allows the non-destructive evaluation of the annulus gas in any receiver, including those installed in the field. It is based on the light spectral emission of the excited gases. The outputs of the measurements are the gas composition and approximate pressure in the annulus space.

It consists of two sets of equipment; a schematic diagram is shown in Fig. 2. The first one is an ionizing source able to excite the gas inside the annulus without damaging the outer glass tube. This ionization generates plasma when the pressure is within a specific working range. Given particular container geometry, the pressure range for the plasma generation depends on each gas or mixture of gases. The limits for some cases are shown in Fig. 3.

Plasma is an energized, gas-like state in which atoms are ionized, releasing free electrons and ions. When those species return to their equilibrium state, the plasma emits light at characteristic wavelengths of the atoms composing the plasma. When plasma is generated, its profile spectrum from 200 to 1100 nm is captured with the second set of equipment consisting of a Maya 2000 Pro spectrometer and its components. From the analysis of these profile spectrums, the gas composition can be determined (Griem, 1997). Hydrogen presents two peaks: H_α at 656 nm and H_β at 486 nm. Nitrogen (air) shows two emission lines, N_{sps} at 330 nm and N_{fps} at 762 nm. Argon presents three characteristic peaks at 750, 763 and around 810 nm.

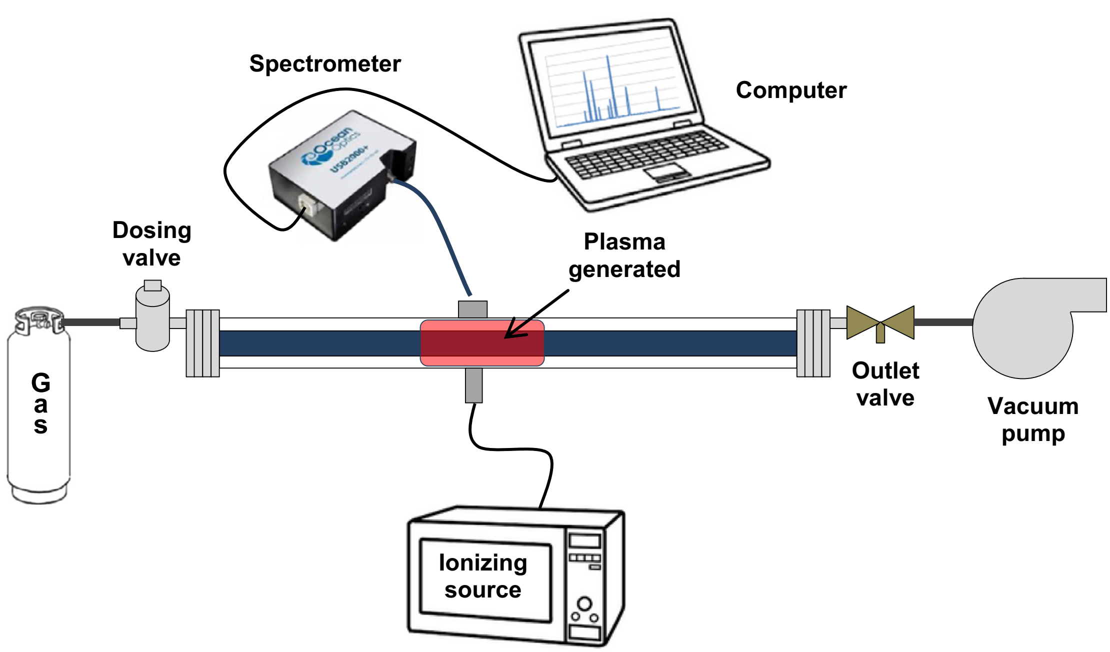

Fig. 2. Experimental set-up for AGA calibration.