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## Degradation effects of maritime atmosphere on metallic components of solar collectors



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### ABSTRACT

The influence of mixed maritime atmosphere on the degradation of metallic components of exposed solar thermal collectors was studied. Corrosion measurements of standard metal samples (unalloyed carbon steel, zinc, copper and aluminum) were performed according to ISO 9226/1992 and ISO 9223/2012 with two different test set-ups; one in the open atmosphere, the other inside a commercial flat-plate thermal collector. Moreover, the influence of defined microclimatic conditions inside the thermal collector on the durability of different absorber surfaces was investigated. The results show extremely high corrosion rates in the open atmosphere for all exposed metals in contrast to the samples inside the solar thermal collector, where high corrosivity was only detected for amorphous metals. The results of optical measurements of the exposed absorber samples show a very good stability of the materials. Additionally, different analytical methods were used for the characterization of corrosion products. This information can be used for the optimization of accelerated aging tests for absorber materials with respect to corrosive environment and salt content.

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### 1. Introduction

Solar thermal collectors have to withstand stress conditions like high temperatures up to 50 °C, high humidity, ultraviolet irradiance or wind and snow loads depending on the geographic position. Saline and corrosive atmospheres are critical stress factors for the metallic components which can cause rapid degradation of absorbers and reflectors. In the course of the qualification procedure Task X, developed in the frame of the IEA Solar Heating and Cooling Programme, the environmental factors temperature, humidity in terms of condensation and atmospheric corrosivity are considered as the most important stress factors for absorber surface durability [1]. To test the resistance against atmospheric corrosivity a standardized test involving the exposure to an atmosphere with a low concentration of sulfur dioxide in high humidity air is used [2]. Although SO<sub>2</sub> is identified as one of the dominating airborne pollutants for atmospheric corrosion in a study conducted by the IEA group [3], the consideration of SO<sub>2</sub> as main corrosion factor for absorber surfaces may be disputable for collectors placed in marine environments as chloride derived from sodium chloride is considered to be major corrosion agent in these regions [4]. Moreover, present studies show that the emission of

SO<sub>2</sub> in the industrialized world has significantly decreased in the last two decades [5].

Solar thermal collectors are frequently used for the preparation of domestic hot water and solar cooling in maritime regions. These regions are characterized by proximity to the ocean and saline atmosphere that can produce very severe corrosion damages on many structural materials, enhance galvanic corrosion and accelerate the deterioration of protective coating systems [4]. Therefore, investigations of the impact of the saline atmosphere on solar thermal collectors are necessary for reducing investment risks as well as for the estimation of operating and maintenance costs in these regions.

Fraunhofer ISE runs an outdoor test site in Pozo Izquierdo on the Canary Islands, Spain, for the examination of the impact of marine atmosphere on the components of solar thermal collectors. Extremely high atmospheric corrosivity compared to other 22 test sites worldwide was measured at this test site in previous exposure programs [6].

The aim of the present study was to investigate the degradation of metallic components of exposed solar collectors by high corrosive atmosphere and to compare the measured corrosion rates for standard metal samples (unalloyed carbon steel, zinc, copper and aluminum) between the open atmosphere and the atmosphere inside the solar thermal collector. Additionally, the

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influence of corrosive conditions inside the thermal collector on the durability of different absorber surfaces was investigated. The exposure study was performed following a similar procedure as used by Carlsson et al. [7].

## 2. Experimental method

### 2.1. Test site description

We exposed solar thermal collectors at the test site Pozo Izquierdo (area of the Instituto Tecnológico de Canarias [8]) in the South-East part of the Gran Canaria Island (N 27° 49' 12"; W 15° 25' 11.999"). The test site is located in spatial proximity to the Atlantic Ocean of 170 m (see Fig. 1). Therefore the main factor for atmospheric corrosivity is the chloride ( $\text{Cl}^-$ ) derived from sea salt aerosols. Hence the test site is located in a semi-urban area, the atmosphere at the test site is characterised as mixed maritime. High amounts of available mineral dust together with strong winds are typical for this test site and can cause heavy soiling on the solar glazing surfaces [9]. The climate at Pozo Izquierdo is characterized as arid with constant ambient temperature with a minimum at 12 °C and maximum at 35 °C. Rainfall is extremely scarce with annual averages of about 160 mm. The relative humidity is stable between 65% and 80% all year round. The corrosion measured in a previous exposition program showed extremely high corrosion rates (corrosion category C5 and CX) for all standard metal samples for the evaluation of corrosivity [6].

### 2.2. The set-up of corrosivity assessment

The corrosion rate measurement of standard metal samples (zinc, aluminum, carbon steel and copper) was performed according to the international standard ISO 9226/1992 [10]. A set of metal samples was exposed parallel in the open atmosphere and inside a commercial flat-plate collector (sheltered atmosphere) in the time period from 02 August, 2013 to 24 July, 2014. The solar thermal collector was operating under stagnation conditions (no thermal energy was extracted from the collector system during testing) and mounted in an angle of 22.5° according to the geographic latitude on the rack facing south. One small sample of each metal (50 × 50 × 1 mm) was exposed on the upper side of the collector. The corrosion samples were fixed on the absorber

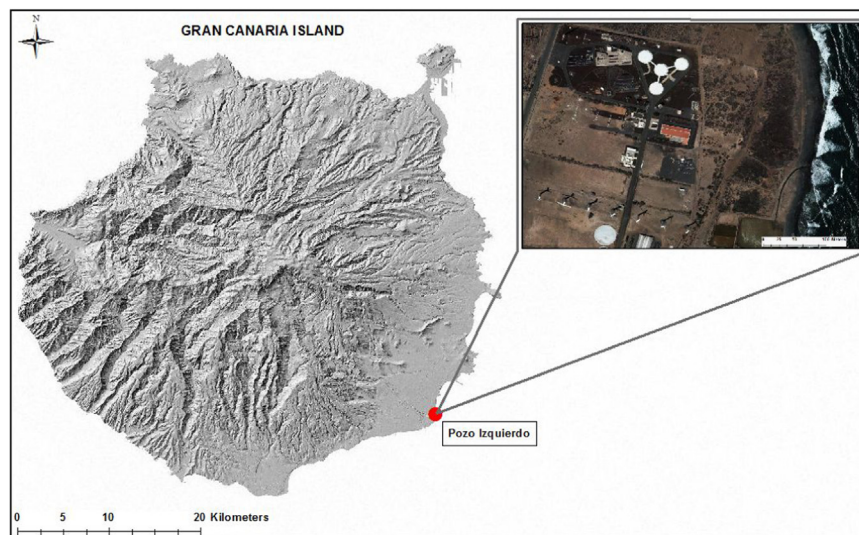
with specially designed sample holders made from polytetrafluoroethylene to ensure that the specimens were galvanically isolated. In the open atmosphere three test samples for each metal (100 × 50 × 1 mm) were used for the exposition at a given angle of 45° above the solar thermal collector. The metal samples in the open atmosphere were fixed to the perforated aluminum plate with polyamide screws to avoid galvanic elements. All exposed samples were prepared uniformly and treated for the exposure as described in Table 1.

In addition to the comparison of the corrosion outside and inside a solar thermal collector, solar absorber materials were tested for the same exposition periods. For a realistic scenario, 10 samples of 200 × 100 × 1 mm were put together with the corrosion samples into a commercial solar thermal flat plate collector on the upper side of the collector. The tested materials were industrially produced solar absorbers. The absorber materials were consisted of an aluminum or copper substrate, respectively.

The aluminum substrates were anodized on both sides. The absorber coating was a multi-layer system applied via physical vapor deposition technique (PVD) consisting of an infrared reflecting layer for a low thermal emission and a metal oxide absorption layer. Some absorber samples had an anti-reflectance layer on the top. One sample with an aluminum substrate was coated with a selective solar absorber paint. The absorber samples were mounted in the same way as by the corrosion samples. The set-up of the exposition is presented in Fig. 2.

After the exposition periods the corrosion rate for all metal samples was determined by weight loss, according to ISO 9226/2012 [10], considering the mass loss, total surface area, metal density and exposure time. The mass loss is the difference between the original weight and the final weight after removing the corrosion products. The corrosion rate is expressed in grams per square meter per year [ $\text{g}/(\text{m}^2 \text{ a})$ ]. According to ISO 9223/2012 [11] the results can be grouped in corrosion classes which are exemplarily presented for copper and aluminum corrosion rates in Table 2.

Meteorological data and other atmospheric factors over the whole exposure period (from 02 August, 2013 to 24 July, 2014) were recorded in order to identify the effect on corrosion under open and sheltered atmosphere at the test site. The meteorological parameters: relative humidity, ambient temperature, global irradiance (horizontally and in plane-of-array) and wind speed and direction were measured every minute. Furthermore, the chloride



**Fig. 1.** The geographic position of the test site Pozo Izquierdo at Gran Canaria. The satellite picture of the test site shows the close proximity to the sea, which has large impact on the atmospheric corrosion.

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