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Solar thermal collectors outdoor testing in saline environment

Daniela Ciobanu[a], Ion Visa[a*], Anca Duta[a*]

[a]*Renewable Energy System and Recycling Research Centre, Transilvania University of Brasov, Brasov, 500036, Romania*

Abstract

For assessing the efficiency, performance and/or durability of flat plate solar thermal collectors, an accelerated outdoor aging test is proposed, based on salt spraying. The flat plate collector is tested using air as working fluid and without circulation. A testing methodology is proposed along with three evaluation criteria, based on the temperature at the collector's outlet and on the outdoor temperature. The ratio of these two temperatures is found to be relevant in outlining the changes resulted due to accelerated aging of the collector, most likely of the sealing, when micro-cracks allow the fine aerosol droplets to penetrate inside the collector, at outdoor temperatures above 25°C. The results need inter-laboratory validation and can represent a step forward in defining a novel quality standard.

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Keywords: solar thermal flat plate collector; aging; saline environment; testing stand;

1. Introduction

There are currently many producers and users of solar thermal systems and solar collectors with quite different performances, all over the world. To assess the quality of any collector, internationally recognized threshold values of certain properties are required, along with a unitary methodology for quality certification, and now-a-days there are many national standardized procedures developed and implemented all over the world; this represents a good start but, since the procedures are not unitary, their comparison can be rather difficult (or even impossible), thus leaving room in the market to a significant amount of fakes; therefore, there is a worldwide interested to achieve and

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[*] Corresponding author.Tel.+40 268 413 000
E-mail address: a.duta@unitbv.ro; visaion@unitbv.ro

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promote standardized global certification [1,2] that should support quality developments at manufacturers level and quality assurance for the users.

Since almost 20 years, solar collectors that work at low to medium temperatures are tested to evaluate the thermal performance in static and quasi-dynamic conditions, along with their durability and resistance as quality indicators. The main durability and resistance tests for solar collectors are [2,3]: internal pressure tests for absorbers; high-temperature resistance test; exposure test; external thermal shock test; internal thermal shock test for liquid-heating collectors; rain penetration test; freezing test and impact resistance test (optional). A draft of a common international standard for solar thermal collectors testing was recently developed as result of the co-work within IEA-SHC Task 43, Solar Keymark Network, SRCC, ISO/TC180 and CEN/TC312, [4], including air heating collectors, PVT collectors, tracked and concentrated collectors; specific focus is set on durability and performance of evacuated tubes, durability and performance of heat pipes for evacuated tubes, durability of absorber surfaces, characterization of glazing, characterization of insulation. This focus is well justified by a large amount of research tests developed for the components of the flat plate collectors, particularly for the absorber plate and glazing, [4,5]. Accelerated aging tests are proposed both in indoor conditions (mainly climatic chamber) but are also reported in outdoor environment, [4,6,7].

One particular aspect might need more attention and this is related to the collectors that are operating on seashore areas. The implementation of small/residential solar-thermal systems is largely spread and preferred locations are in warm areas, particularly on the seashore, in summer resorts. Here, flat plate collectors are mainly used for the preparation of domestic hot water and their technical and market competitiveness is determined by the economic factors (initial and operation costs, interest rates, payback time), their efficiency, and, last but not least, their lifetime. Operating in a seashore area has several particularities given by the salty environment in the atmosphere which contains fine aerosols of seawater in air, produced by the constant breeze. The effect of salty environment on metals corrosion is well known and can affect the metal casing, and corrosion tests are already existent (e.g. ASTM B 117 and ISO 9227 salt spray corrosion resistance test of coated samples); these could be easily translated to solar-thermal collectors. Also salt spraying is reported as testing procedure of the reflecting layer for solar thermal facades in the standard SO/CD21207 method A, [8].

Another effect of combined heat and salty aerosols could be expected on the sealing and, to the best of our knowledge, there are no reports on tests regarding the tightness of low-temperature or medium -temperature thermal collectors. The tightness of a flat plate solar collector is good but not at the level of a PV module, and the seals – subjected to quite large temperature variations, are usually less resistant as compared to the usual lifetime of a collector (20…25 years). The results is that water vapours or very small liquid droplets can enter inside the collector and, during night, will promote condensation on the inner side of the glazing and on the absorber plate; when implemented in the seaside areas, the salty aerosol atmosphere is also likely to penetrate inside the collector and – condensed - will affect the glazing (inorganic or organic glass) but will mainly affect the absorber plate, inducing erosion/corrosion of the spectral selective coating, thus reducing the conversion efficiency due to fast aging.

Lately this problem was approached in an analysis on glazing aging, developed in six different implementation sites, including one maritime site, [6]. Although responsible for the fast degradation of their performances, aging tests in saline environments are not standardized yet for the collectors.

This paper presents the preliminary results on outdoor testing of a solar thermal flat plate collector under “salt spray”, developed as a saline aerosol. A testing methodology is proposed and there are analysed relevant parameters that can be used as criteria in appreciating the durability of the entire collector.

2. Testing infrastructure and methodology

2.1. The testing infrastructure

Experimental test were performed on the rig implemented on the rooftop of the laboratory building of the R&D Centre Renewable Energy Systems and Recycling, in the Research Institute of the Transilvania University of Brasov (latitude 45°66’ N, longitude 25°61’, 600m above the sea level, with a continental temperate climatic profile).

The weather data were monitored and registered (each 10 min) using a Delta T weather station, with an ES2 energy meter (for global and diffuse radiation, ±3% accuracy) and with temperature, wind speed and direction, and atmospheric humidity sensors.

The testing rig presented in Fig. 1 was designed considering the specific objectives of the testing procedure using saline aerosols and consists of :

1. Flat plate solar collector with the gross area of 2.32 m^2. The collector has a non-coated aluminum frame and the back panel is made from aluminum-zinc; the glazing consists of solar glass with 3.2 mm thickness; the absorber plate is of cermet type with a TiO_2 protective and anti-reflection layer, and the thermal fluid circulates in a meander-shaped copper pipe; the thermal insulation is made from mineral fiber. The collector is installed facing South, and is fixed and tilt at 45^0;
2. Nozzles for spraying the saline aerosol; 25 nozzles are equidistantly installed on a pipe, with 12.7 cm space between them, allowing a homogeneous coverage of the collector's surface. ;
3. Plastic (PVC) trough to collect the saline water at the bottom of the collector;
4. Storage tank (30 L) for the saline solution; a NaCl solution was used in the test with the 3.5% weight concentration, similarly to the value recommended in the metals corrosion standards;
5. Recirculation pump (T.I.P. GPK46/42) with controllable flow;
6. Flow-meter (FIP FSIV032T, accuracy ± 1.875%).

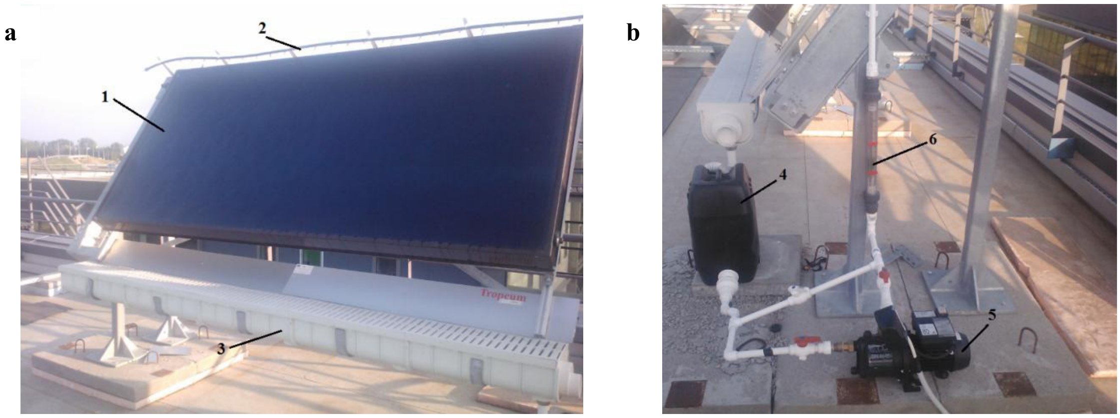


Fig. 1 Testing rig:(a) front view and (b)right side view

The temperature and the humidity inside the collector were registered using a TPI597 device (Wales, ±0.5% accuracy).

2.2. The testing methodology

Testing was conducted on the flat plate solar collector having air in the pipes and no circulation. This setup was chosen considering the different specific heats of air (1.005 kJ/kg K) and water (4.180 kJ/kg K) and the very large density differences (1000 kg/m^3 for water and 1.12…1.29 kg/m^3 for air); using air allows thus sensing small variations in the temperature inside the pipes, under the outdoor irradiation conditions.

The tests covered a period of 20 days, in July - August 2013, a period which usually is characterized by sunny days.

The testing procedure runs with the following steps:

1. Cleaning with tap water the collector outer glazing, for removing dust and residual salt;
2. Continuous spraying of the salty aerosols during the time interval 8:55 – 15:15; the saline water flow was kept constant at 500 L/h;
3. Measuring the inlet and outlet air temperatures inside the collector (each 10 min.) and reporting the data corresponding to a low radiation period (in the morning, at 9:00), to a high radiation period (at noon, 12:00) and during the afternoon, at 15:00 o' clock, also to check the thermal inertia of the system.. The outdoor conditions at these moments were also used, as given by the weather station.

3. Results and discussion

The testing work aimed at identifying a correlation between the input data (global radiation, and/or outdoor temperature, and/or wind speed) and the output parameters. The input data with the largest influence on the solar energy conversion are: the global solar radiation incident on the module G_T, the outdoor temperature T_a and the wind speed. These are comparatively presented for the 20 days for the data recorded at 9:00 (Fig. 2), at 12:00 (Fig. 3) and 15:00 (Fig. 4).

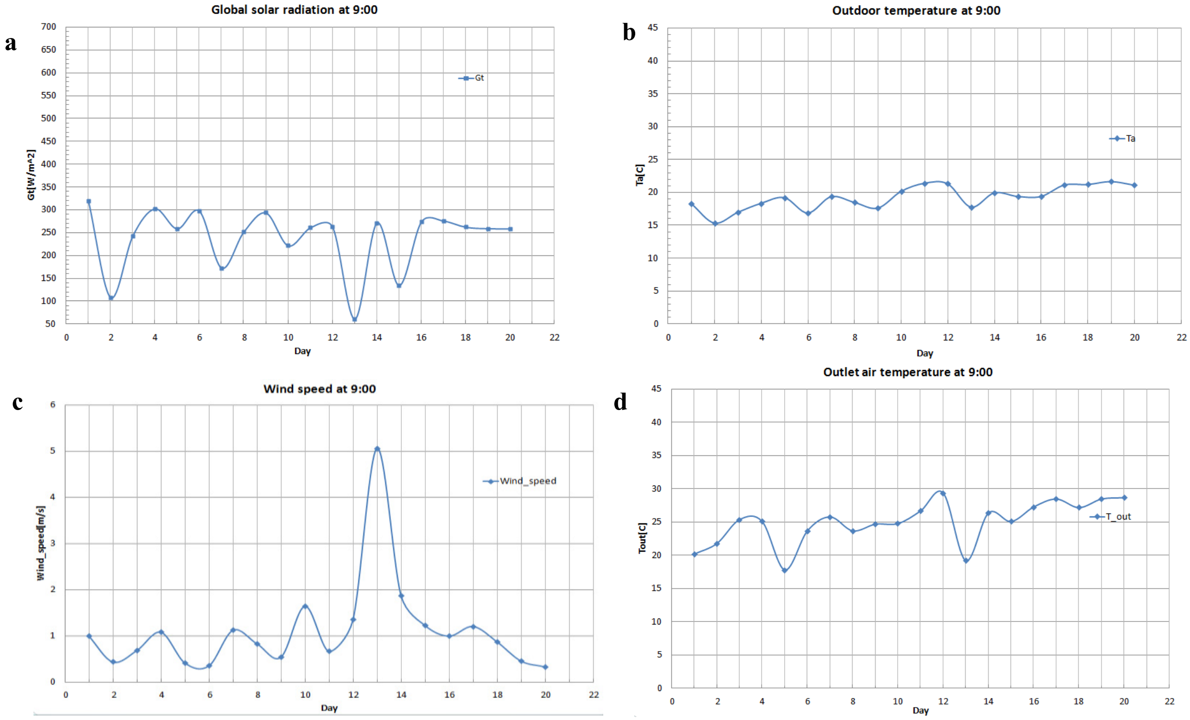
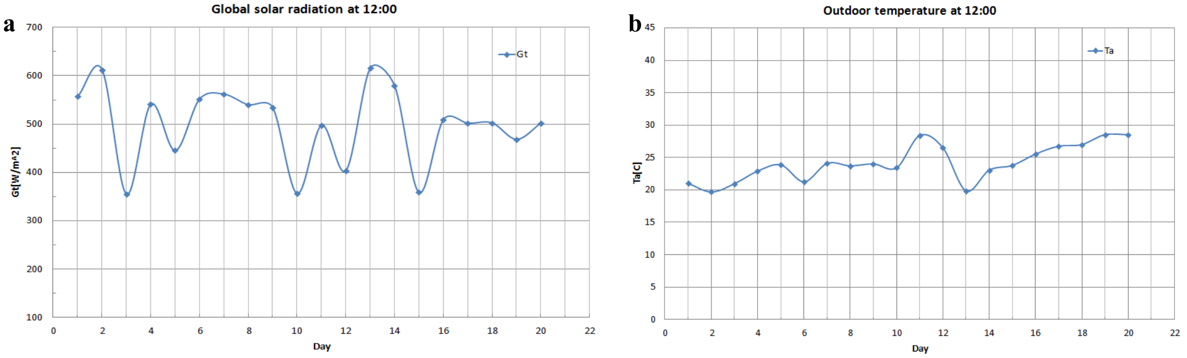


Fig.2 In-field measurement at 9:00 for (a)global solar radiation, (b) outdoor temperature, (c) wind speed and (d) outlet air temperature in the collector



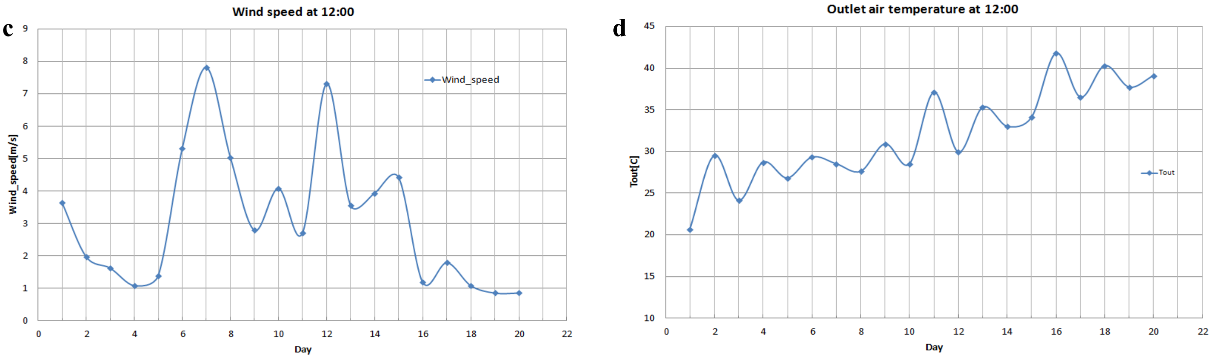


Fig. 3 In-field measurement at 12:00 for (a)global solar radiation, (b) outdoor temperature, (c) wind speed and (d) outlet air temperature in the collector

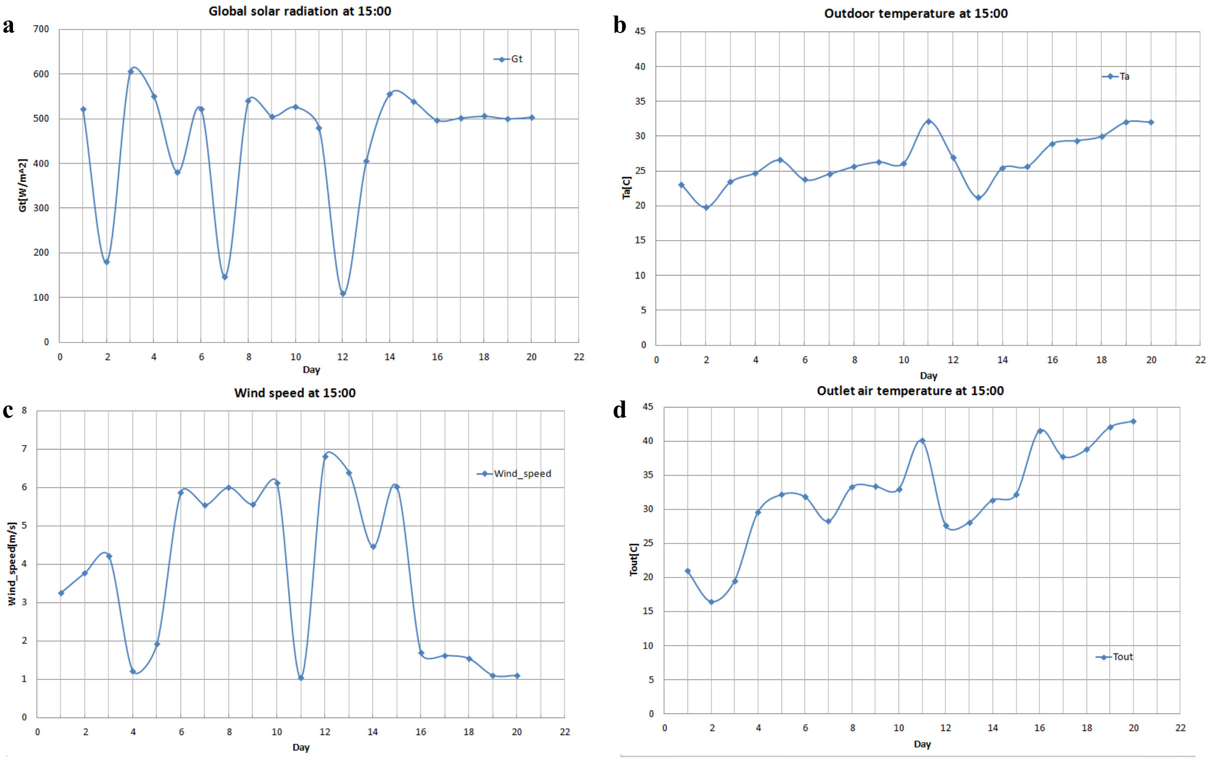


Fig. 4 In-field measurement at 15:00 for (a)global solar radiation, (b) outdoor temperature, (c) wind speed and (d) outlet air temperature in the collector

During the morning hours, the input data show rather low incident radiation and a steadily increasing temperature, up to 22°C in the end of the interval. At noon and at 15:00 the radiation profile and especially the temperature variation are almost identical and there is not a linear correlation between radiation and outdoor temperature.

One key problem that had to be answered was related to selecting the output parameter with the most significant variation during the tests. One obvious parameter could be the temperature increase in the collector as result of the solar to thermal energy conversion. As the experimental data show, the temperatures at the collector's inlet and outlet have slightly different values, and in these preliminary experiments the temperature at the outlet was further considered.

Based on the in-field data several conclusions can be outlined:

1. Global radiation and temperature at the collector's outlet have not a correlated variation in the experimental conditions; this proved to be particularly true, for the entire testing interval, for radiation values bellow 500 W/m^2 thus, if translating these types of experiments on an indoor testing rig, radiation should be set at values higher than 500 W/m^2. This result can be correlated also with the "cooling" effect of the aerosols (T = 18…20°C) and with the partial reflection induced by the thin aqueous film of salty solution formed on the collector.

2. The outdoor temperature significantly influences the temperature at the collector's outlet;

3. The cooling effect of wind is significant at speeds above 5 m/s, especially when combined with low radiation; this is a well-known effect (embedded in the already existing standards) and should be considered also for further outdoor testing certification conditions.

Testing aimed at an accelerated aging of the collector's sealing and it was expected to outline some variations in the output property, initially considered to be the outlet temperature of the collector. As expected, during the first testing days no obvious variations were registered. Still, these temperature data show a constant increase after Day 12 and this could be correlated with a modification, most likely of the thermal properties of the absorber plate. In saline aqueous environment the alumina matrix of the cermet coating can form novel compounds (as AlOOH and AlOCl) that can change the porosity leading to momentary improved performances. Unfortunately, these compounds tend also to form in time powders that can exfoliate from the metal substrate, leading to an accelerated degradation of the absorber. Long time testing should bring supplementary information that will allow identifying the mechanism responsible for this behavior.

Considering the better correlation between the outdoor and outlet temperatures, two other criteria were proposed and investigated in terms of relevance:

- The difference between the outlet and outdoor temperatures, T_{out} - T_a, Fig. 5;
- The ratio of the outlet and outdoor temperatures, T_{out} / T_a, Fig. 6.

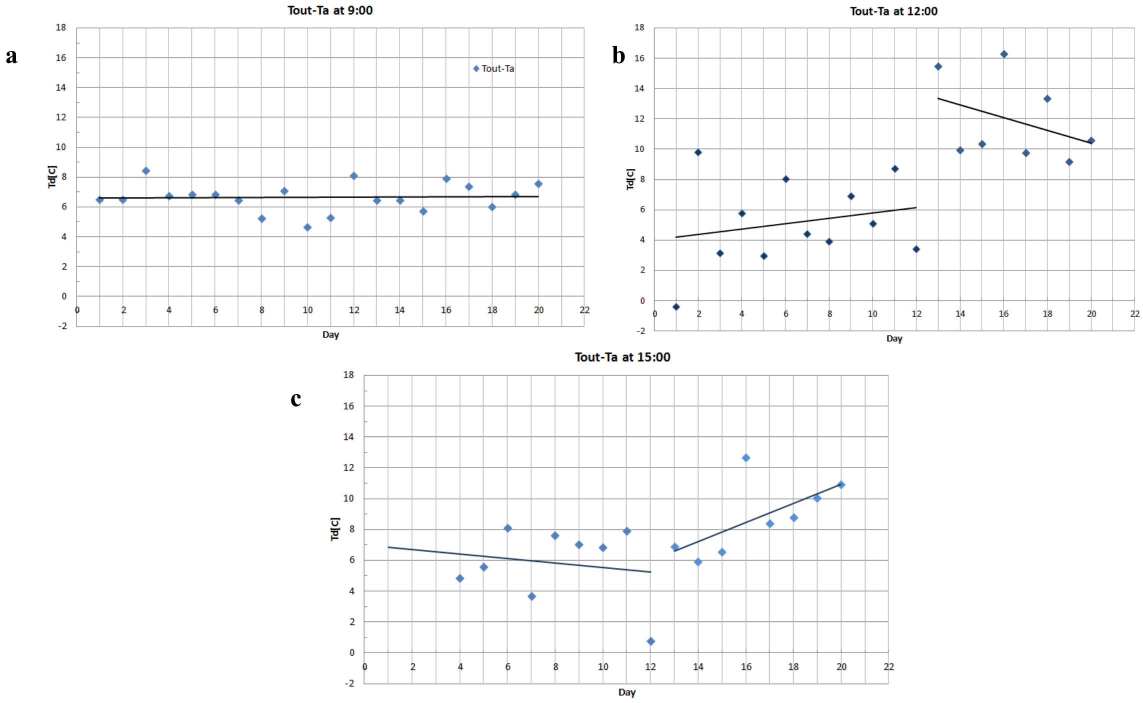


Fig. 5 Difference of outlet air temperature and outdoor temperature for (a) 9 o'clock; (b) 12 o'clock and (c) 15 o'clock

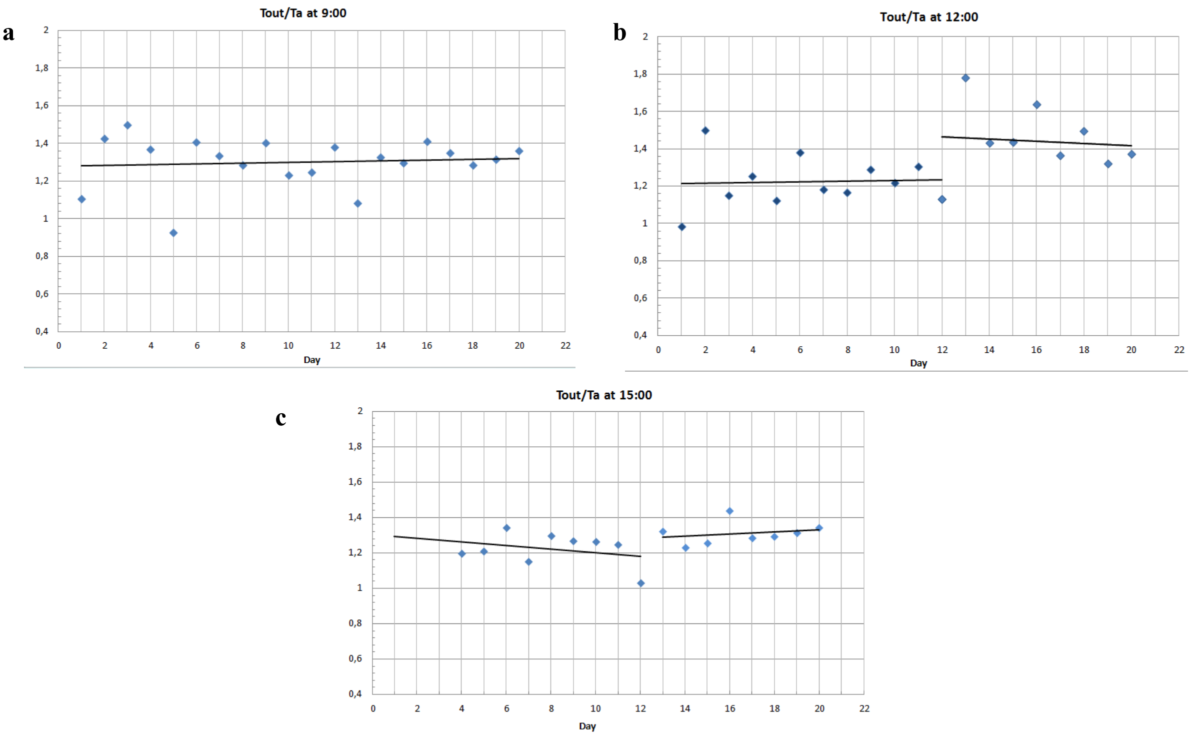


Fig. 6 Ratio of outlet air temperature and outdoor temperature for (a) 9 o'clock; (b) 12 o'clock and (c) 15 o'clock

Both criteria show that after Day 12 there is a significant difference in the trend of the values registered at 12:00 and at 15:00 and are not observed at 9:00 o'clock. This may confirm our assumption that this effect is related to the sealing aging, leading to micro-cracks that can expand when heated (after prolonged stay under solar irradiation) and can be more easily penetrated by aerosols. In terms of relative variation, the criterion based on the ratio of the two temperatures may be more evident.

These assumptions are confirmed by the changes in the solar collector, as outlined in Fig. 7:

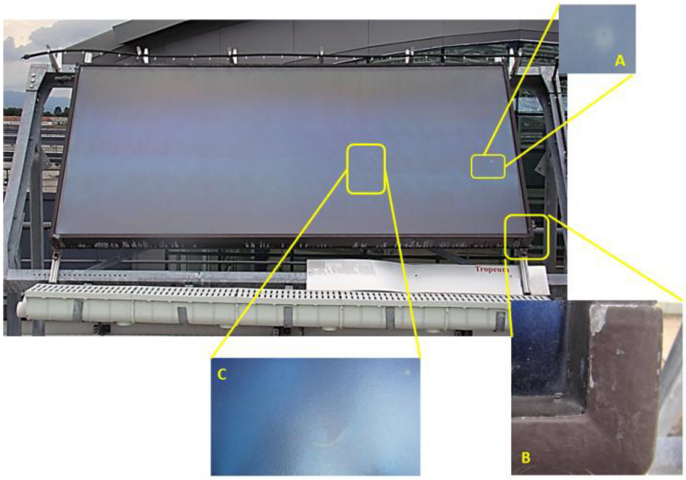


Fig. 7 Typical aging of the collector after 20 days of testing: (A) white spots on the absorber plate; (B) metal frame corrosion and sealing cracks; (C) profiling on the absorber plate

Several aging proves were identified:

- White spots on the absorber plate, with various dimensions, on average 1 spot/ 625cm^2;
- Absorber linear aging, in regions that cover the pipe serpentine; these thin lines prove an increase in the thermal sensitivity of the material and can be responsible for further extended corrosion/erosion;
- As expected the metal frame is corroded, although the initial combination (steel / zinc, thermally deposited / epoxy resin) was a good choice of the manufacturer;
- Visible cracks on the sealing, particularly in the corners.

Based on these data, one may conclude that the durability of the solar collectors in saline environment could be estimated by outdoor testing in the following conditions:

- Time duration of the testing period should be 20 days or longer, the major changes in solar collector behaviour can be observed after 12 days; longer term investigations should be done for observing the degrading path; once started, degrading can follow continuously or stepwise and this could be observed based on the variation of the T_{out}/T_a ratio.
- The outdoor temperature for collecting data is recommended above 25^{0}C, when micro-cracks expansion can occur and allow the aerosol penetration inside the collector.
- The wind speed is recommended below 2m/s, for avoiding the cooling effect that may distort the results;
- Global radiation in solar collector plane should be larger than 500W/m^2.

Experimental testing should be expanded on a period of 3…6 months that can be established based on in-field experiments (leading to relevant data) and in agreement with the timeframe that will be finally decided for other tests applied to solar-thermal collectors, through the joint European standard(s).

4. Conclusions

The results so far obtained show that outdoor testing of solar thermal collectors in saline environments can lead to relevant results in appreciating their performance, durability and lifetime. Factors that should be considered are the length of the testing sequence, the temperature variations and the wind speed during testing in weather conditions without precipitations. Long term experiments and inter-laboratory validation need to be developed before this type of testing could become part of a standardized quality assessment procedure.

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