ABSORBER SURFACE DURABILITY STANDARD TESTING ISO 22975-3 VS. MEASURED THERMAL STRESS AT EXTREME TEST SITE

Thomas Kaltenbach[1], Markus Heck[1] and Karl-Anders Weiß[1]

[1] Fraunhofer-Institute for Solar-Energy-Systems ISE
Heidenhofstr. 2, 79110 Freiburg, Germany

Abstract

Solar absorbers, as a key component in solar thermal collectors, are in the focus of this paper. A well introduced durability testing method for the solar absorber is the testing procedure described in ISO 22975-3 [1]. This standard testing procedure is applicable to the determination of the long term behavior and service life of selective solar absorbers for use in vented flat plate solar collectors.

Different samples of solar absorbers on aluminum and copper substrates are characterized before, during and after the accelerated ageing tests and outdoor exposure with various methods, including FT-IR spectroscopy and microscopic technologies like AFM microscopy to measure the degradation on different scales.

It turned out, that the corresponding testing time of the procedure for high temperature test was less than in the standard ISO 22975-3. Therefore, the standard testing procedure is testing at higher thermal loads then the extreme test sites with high absorber temperature in constant stagnation mode.

Keywords: *Solar absorber, components for collectors, durability, accelerated ageing, optical characterization*

1. Introduction

Depending on their location and prevalent climatic conditions, the components of solar thermal collectors have to bear high climatic and mechanical stresses. Besides high temperatures, UV-light, wind, snow, humidity or saline and corrosive atmospheres can be causes for a rapid degradation of materials and components.

Despite these well-known obstacles for solar thermal installations in extreme climates, the aging processes with regard to different climatic and operational conditions are only partially analyzed. To qualify and enhance the durability of solar thermal systems and improve the opportunities on a world-wide scale, the development of suitable accelerated aging tests is necessary. The project “SpeedColl”[2] is dedicated to the research on these issues.

The aging effects occurring in solar collectors with glass covers are determined primarily by the temperature level in the collector. This temperature level has significantly increased during the last years due to the enhancement of the collector efficiency and the trend towards systems with higher solar fractions with the resulting increase in stagnation times and temperatures. Furthermore, durability analyses of new products on the market such as spectrally selective absorber layers are needed, since only little is known about their long-term behavior.

Next to the influence of increased temperatures, other causes for aging have to be analyzed too, especially UV-radiation, moisture and the influence of saline atmospheres. Furthermore the frequent use of solar thermal collectors in Mediterranean regions for the preparation of domestic hot water generation and solar cooling, a quality check regarding the impact of the saline atmosphere predominating close to the sea-shore in these countries is necessary. This will be emphasized in detail in the “SpeedColl” project. This paper will focus on the influence of the stress factor temperature on the absorber. The samples are provided by the industrial project partners.

Of all components in solar thermal systems, solar collectors experience the highest climatic and mechanical stress. They are subjected to high temperatures and, depending on the location, variable and extreme weather conditions. Just as coastal and sun-rich regions offer large potential for solar energy use; the systems installed in these areas

doi:10.18086/swc.2017.19.06 Available at http://proceedings.ises.org

are exposed to especially high levels of UV radiation, humidity and salt air. As a result, the collectors often age and degrade faster.

In “SpeedColl” actual environmental stress data such as humidity, UV radiation, temperature and salt concentration are determined. The data collection varies from tests carried out in alpine, moderate and maritime locations through to measurements in arid and tropical regions. Test stands are installed on the Zugspitze, the highest mountain in Germany, as well as in Freiburg, Stuttgart, Gran Canaria, the Negev Desert and in India. Additionally the solar collectors and components undergo accelerated aging tests in the laboratory. Using the collected data, the researchers validate the procedures of the aging tests, which provide information about the collector’s thermal performance over its entire lifetime. The results also serve as a basis for standardization.

2. Absorber surface durability testing

The absorber surface durability testing specifies a failure criterion of a solar absorber based on changes in optical performance of the absorber. The optical properties of interest are the solar absorptance α and the thermal emittance ε. The testing according to ISO 22975-3 specifies durability testing procedures focused on resistance to high temperatures and condensation of water on the absorber surface as well as high humidity.

Within the test procedure, the reference of the thermal load for the assessment of the thermal stability of the absorber coating was measured in a flat plate collector. The collector was exposed in Freiburg, Germany. The absorber temperature was measured in stagnation over one day of clear conditions with a maximum global irradiation of 930 W/m². The total annual load assumed 30 days of stagnation. The maximum stagnation temperature was 184°C. [3].

In the “SpeedColl” project, the absorber samples are exposed to outdoor weathering at five test sites with different climatic conditions with continuous monitoring of the micro and macro climatic conditions. Since a direct exposure of absorbers is not adequate to the real situation of the solar absorbers in solar thermal collectors, the test samples were mounted above the solar absorber with purpose-built galvanically insulated spacers in a commercial solar thermal collector. The absorber temperature is continuously monitored. To receive also information of the corrosivity of the micro climate inside the collector, test coupons of four different metals are placed inside the collector, too. The ambient climatic conditions in terms of corrosivity are also measured as a reference next to the test collector [4].

The temperature of the solar absorber inside the test collector is measured continuously during exposure in order to set up a data base for the development of suitable accelerated lifetime tests.

Accelerated ageing tests with a variation of the relevant parameters, temperature and condensed water on the absorber surface are performed in climatic cabinets. Especially tests with condensed water at high temperature levels are used for the qualification of the materials since this is seen as the most demanding factor and relevant for the application of solar thermal systems in sunny regions.

For collectors placed in marine environments chloride ions from sodium chloride are considered to be major corrosion agent in these regions [5].

3. Characterization methods

The spectral measurements were carried out with a Fourier transform spectrometer Bruker Vertrex70 equipped with two integrating spheres (a PTFE coated sphere for the shorter wavelength-range ($\lambda < 2{,}0\ \mu m$) and a diffuse-gold coated sphere for the IR ($\lambda > 1{,}7\ \mu m$) in order to measure both the directly reflected and the scattered radiation. The diffuse part of the reflectance was calibrated with a PTFE standard from National Institute of Standards and Technology (NIST) for the solar range and from National Physical Laboratory (NPL) for the thermal range. The specular part in the solar and the infrared ranges was calibrated with an aluminum mirror from NPL. The accuracy of the reflectance data was better than 1 % in the solar range and better than 2 % in the IR. The solar absorptance/reflectance was calculated by weighted integration of the spectral reflectance with the solar spectrum AM 1.5 according to ISO 9845-1. The thermal emittance was calculated by weighted integration of the spectral reflectance with the Planck Black Body radiation distribution at a temperature of 373 K.

4. Weathering tests

The samples are exposed to outdoor weathering at five test sites with different climatic conditions under continuous monitoring of the climatic conditions (temperature, humidity, wind, precipitation, UV) and the collector micro climate (temperature and humidity inside the collector). In order to gain worst-case-data some of the test sites are positioned in extreme climates with very harsh conditions (Table 1).

Tab. 1: Exposition of collectors at locations with extreme climates

Climates	Location
Tropical	Kochi, India
Alpine	Schneefernerhaus, Zugspitze, Germany
Aride	Sede Boker, Negev Dessert, Israel
Maritime	Pozo Izquierdo, Gran Canaria, Spain
Moderate	Stuttgart and Freiburg, Germany

Figure 1 shows the temperature distribution of the same commercial vented flat plate solar collector type at the 5 different explosion sits within the “SpeedColl” project. The collectors were not actively cooled; therefore they were in constant stagnation mode.

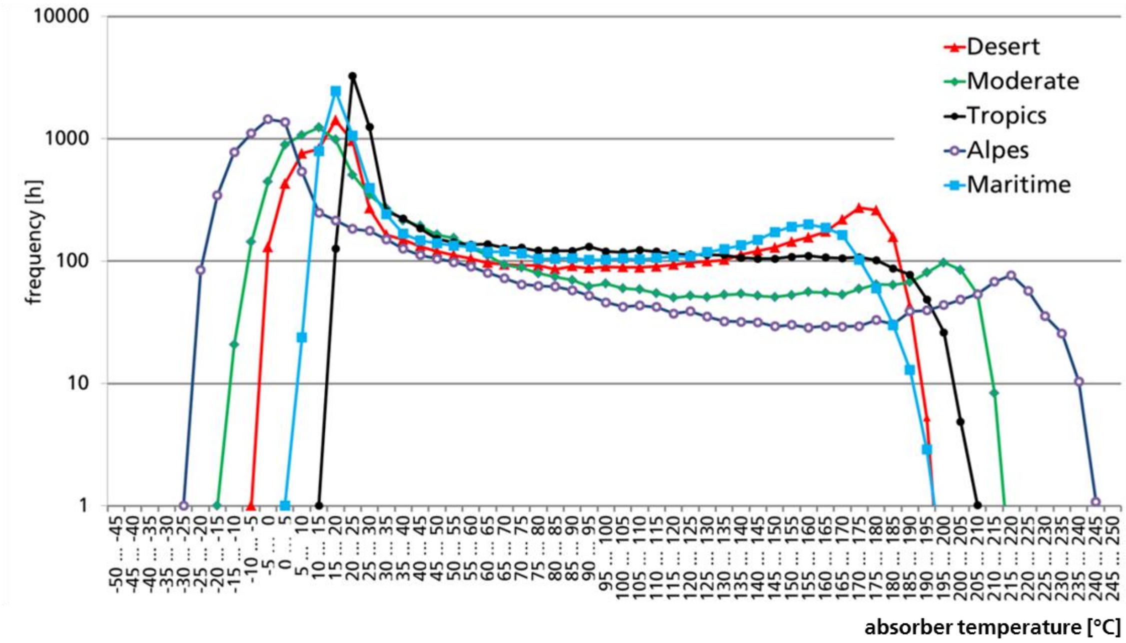

Fig. 1: Histogram of the absorber temperatures [°C] at different exposition sites, measured period from 12/2013 to 11/2014, Negev desert (arid) in Israel; Freiburg (moderate) in Germany; Kochi (tropical) in India; Zugspitze (alpine) in the German Alps and Gran Canaria (maritime) in Spain

The alpine exposition site reached the biggest temperature spread of the absorber temperature with minimum temperature of -30°C and maximum temperature of 245°C.

5. Service life testing

To measure the load during an operating time of one year of the absorber coating the effective mean temperature T_{eff} turns out to be a suitable parameter. It is defined in equation 1.

$$\exp(-\frac{E_T}{R} \cdot T_{eff}^{-1}) = \int_{T_{min}}^{T_{max}} \exp(-\frac{E_T}{R} \cdot T^{-1}) \cdot f(T) \cdot dT \qquad \text{(eq. 1) [6]}$$

with

f(T)	the temperature frequency function for the observed load over one year
T_{max}, T_{min}	maximum or minimum absorber temperature of the load
E_T	activation energy

For thermal degradation f(T) is the time in one year, during which the absorber temperature lies between T and T+dT. For degradation by condensation and high humidity, f(T) is the time in one year, during which the absorber temperature lies between T and T+dT, and the relative humidity in the collector exceeds 99% or condensation takes place on the absorber.

The effective mean temperatures of the same commercial vented flat plate solar collector type with a chosen activation energy of 50 kJ/mol as a lower estimate at the 5 different explosion sits within the “SpeedColl” project are shown in figure 2.

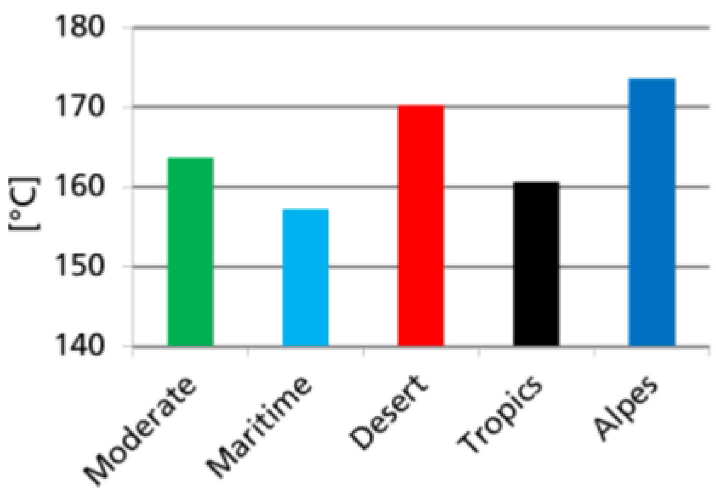

Fig. 2: Effective mean absorber temperature [°C] at different exposition sites, measured period from 12/2013 to 11/2014 with an activation energy of 50 kJ/mol, Freiburg (moderate) in Germany; Gran Canaria (maritime) in Spain; Negev desert (arid) in Israel; Kochi (tropical) in India and Zugspitze (alpine) in the German Alps

The alpine exposition site led to the highest effective mean temperature of 174°C. With this measured thermal load we used the same time transformation function for the assessment of the thermal stability of the absorber coating like it was done in the standard testing procedure ISO 22975-3.

The corresponding testing time for the procedure for the execution of the high temperature testing to 25 years lifetime based on the Arrhenius relationship is shown in figure 3 for three different testing temperatures as a function of the activation energy.

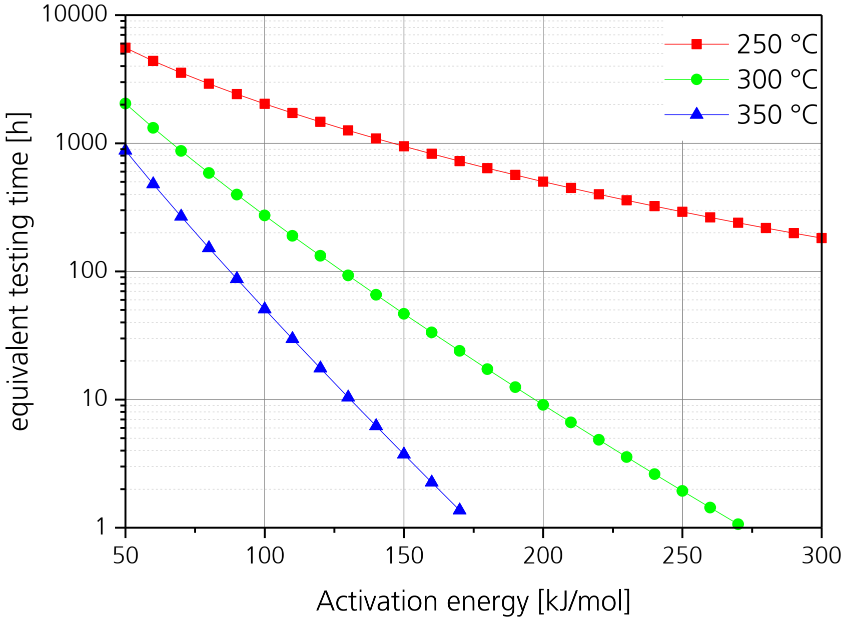

Fig. 3: Testing time equivalent to 25 years lifetime with measured thermal load of Zugspitze (alpine) in the German Alps for 250°C, 300°C and 350°C testing temperature as function of the activation energy

In figure 4 the corresponding testing time for the procedure for the execution of the high temperature to 25 years lifetime according to ISO 22975-3 is shown for three different testing temperatures as a function of the activation energy.

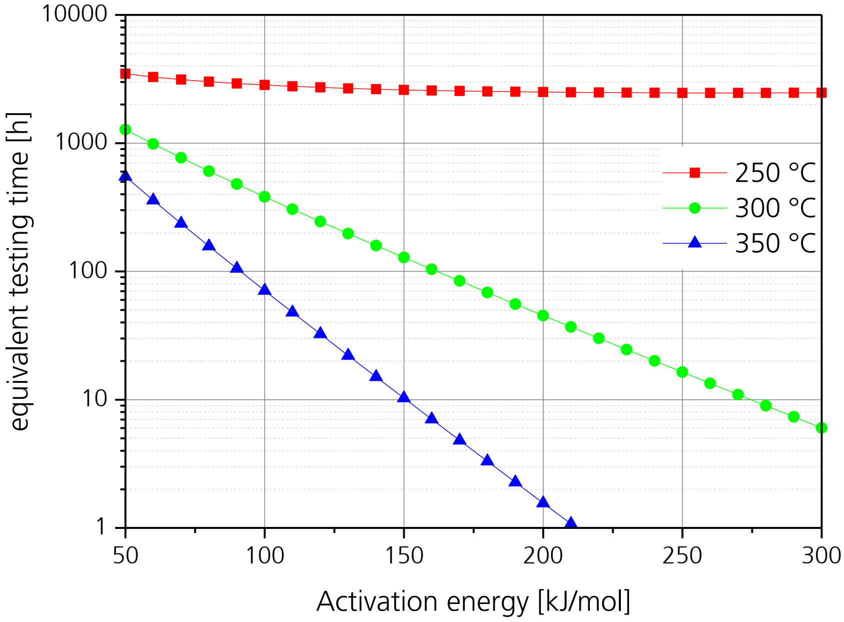

Fig. 4: Testing time equivalent to 25 years lifetime according to ISO 22975-3 with thermal load of Zugspitze (alpine) in the German Alps for 250°C, 300°C and 350°C testing temperature as function of the activation energy

It turns out, that the corresponding testing time for the procedure for the execution of the high temperature test determined in the project was less than the testing time in the standard. For example with an assumed activation Energy E_T of 100 kJ/mol the testing time equivalent at a testing temperature of 300°C is 273 h and for ISO 22975-3 the testing time equivalent is 381 h.

Therefore, the standard testing procedure is testing at approx. 40% higher thermal loads then the extreme alpine test site with high absorber temperature in constant stagnation mode.

6. Conclusion and outlook

The relevant physical properties of the material samples were measured before and after the exposure to accelerated ageing tests and outdoor weathering. The results of the initial optical characterization of the test-samples proved a very good homogeneity. The standard deviation out of 21 test panels for the solar absorptance value α is 0,001 and for the thermal emittance value ε the standard deviation is 0.003. This assumes an excellent production quality

It turned out, that the corresponding testing time of the procedure for high temperature test for the alpine test site was less than in the standard. Therefore, the standard testing procedure is testing at higher thermal loads then the extreme alpine test site with high absorber temperature in constant stagnation mode.

Thus the standard testing procedure ISO 22975-3 fully covers the aging behavior of absorbers in terms of high temperature loads even at the condition measured at the extreme alpine test site, where the highest absorber temperatures within the “SpeedColl” project were measured.

The effects of high humidity and condensed water in terms of the stability of the absorber coating will be addressed in the current “SpeedColl2” project.

7. Acknowledgements

The authors would like to thank the industrial partners and the German Federal Ministry for Economic Affairs and Energy (FKz. 0325969A) for their support and funding.

8. References

[1] ISO 22975 Part 3:2013, Solar Energy-Collector components and materials, Absorber surface durability

[2] Development of Accelerated Aging Tests for Solar Thermal Collectors and their Components, www.speedcoll2.de

[3] Accelerated Life Testing of Solar Energy Materials – Case study of some selective solar absorber for DHW systems. A Technical report of Task X Solar Materials Research and Development of the International Energy Agency Solar heating and Cooling Program; B. Carlsson, U. Frei, M. Köhl, K. Möller; SP-Report 1994:13, ISBN 91-7848-472-3

[4] ISO 9226:1992 Corrosion of metals and alloys - Corrosivity of atmospheres- Determination of corrosion rate of standard specimens for the evaluation of corrosivity

[5].Slamova, K., I. Duerr, T. Kaltenbach, M. Köhl, 2016. Degradation effects of maritime atmosphere on metallic components of solar collectors. Solar Energy Materials & Solar Cells 147, 246–254

[6] ADVANCED PROCEDURE FOR THE ASSESSMENT OF THE LIFETIME OF SOLAR ABSORBER COATINGS; Köhl, M.; Heck, M.; Brunold, S.; Frei, U.; Carlsson, B.; Möller, K.: Advanced Procedure for the assessment of the lifetime of solar absorber coatings. Solar Energy Merials and Solar Cells, Volume 84, Issues 1-4 , October 2004, Pages 275-289